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Development of a Prototype for Point Load Testing of Aggregates

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Abstract:	This report presents results of a study carried out by Franklin Geotechnical Engineering Ltd. in collaboration with the University of Waterloo. The overall aim has been to investigate the use of the point load test for the evaluation of aggregates, and to develop a prototype testing machine specifically for this purpose. This study included the development, by MTO, of a purpose-designed tester with great sensitivity, which was used to evaluate accuracy limitations and size and shape effects. Seven Ontario rock types were machined into cores from 6.7 to 70 mm diameter, and crushed into aggregates from 6.7 to 26.5 mm. The program included 735 tests on aggregate particles and 502 on core, with supplementary index tests and thin section studies. Results showed that some 15 to 20 particles can be tested in less than five minutes to give a strength value accurate to about plus or minus 20 to 50% of the mean. This accuracy can be improved by further modification of the tester. Size-strength effects deviated from those reported in the literature, probably because of measuring and platen friction inaccuracies. An interim size correction procedure is recommended that refers all results to a standard 20 mm diameter. It is also recommended that sizes in the range of 16 to 26.5 mm should be tested for the best results, although with an improved tester it should also be possible to employ aggregate in the size range of 6.7 to 19 mm. The outcome of tests for specimen flakiness D/W was close to 0.5 and by making use of this result, shape effects were easy to correct. D/W should be estimated or measured to the nearest 20% for a 20% error in strength estimation.
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1. INTRODUCTION

1.1 The Point Load Strength Test

This test was introduced in 1972 by Broch and Franklin (1) and has since been widely employed as an index test to classify the strength of rock materials. The equipment is portable. The specimens can take the form of unmachined core cylinders, core disks or even irregular lumps. As a result, the test is simple, quick and inexpensive. Several hundred specimens can be tested in the time required for just one uniaxial compressive strength determination.

The "Point Load Strength Index I_{s50}" is measured by loading a rock specimen between conical platens until it breaks. The failure load P and platen separation distance D are measured. I_{s50} is calculated as a function of P and D.

1.2 Applicability to Aggregates

In a 1978 proposal to the Ontario Ministry of Transportation and Communications (MTC) we suggested that the test had potential as a method for evaluating the quality of aggregates, although to date it had not been used for that purpose. Indeed, the testing of fragments smaller than 25 mm, typical aggregate particles, had been specifically excluded by the international "Suggested Method" for the test in existence at that time. This limitation has been removed in a subsequent revision of the Suggested Method (6), largely as a result of current research described in this report.

Strength is an important property of aggregates because it influences the strengths of concretes and asphalts in which the aggregates are used, and because it is related to a number of other performance properties such as strength of bond, abrasion and frost resistance.

Aggregate strength is determined indirectly by MTC as a part of the Petrographic Number method in which aggregate particles are categorized as "hard" or "soft, friable etc.", "weathered" or "unweathered", using visual observation and scratch tests that are somewhat qualitative and imprecise. A simple yet quantitative and reproducible strength test would be a useful adjunct to Petrographic Number determination or could stand on its own as one of several methods for aggregate evaluation.

Reasons for the earlier size limitation in point load testing were firstly, a lack of experience in testing the small particle size range, and secondly, inadequacies in the available testing machines which were insufficiently sensitive for the measurement of small failure loads and platen separation distances. We therefore proposed a study to investigate the feasibility of extending use of the test to small sized particles.

1.3 Earlier Feasibility Study

A feasibility study was authorised as MTC R & D Project 22312. 4,000 aggregate particles of various rock types and sources were tested, and the results were compared with Petrographic Number and with field observations of aggregate durabilty.

The results were reported in May 1981, concluding that "the point load testing procedure was found to be feasible and promises to be a useful method for aggregate testing". The research had demonstrated the following:

- That aggregate-sized particles could be tested as easily and quickly as larger fragments and core.
- That the test discriminated well between stronger and weaker particles of the same rock type, as confirmed by the correlation obtained between point load strength and the designations "hard", "soft" etc. assigned by visual and scratch tests during Petrographic Number determination.
- That the test results correlated with MTC's observations of the field performance of the same aggregate types.

The results of this feasibility study were inconclusive, however, firstly because of the use of a standard testing machine which proved to be insufficiently sensitive for precise measurements on small particles, and secondly because of the choice of Amabel dolostone as the main rock type for the test series. The dolostone proved to be unusual in its behaviour, partly due to presence of large vugs, and gave abnormal size-strength relationsnips and correlations with uniaxial compressive strength.

Several questions had still to be answered before the test method could be used with confidence for aggregate testing. These set the terms of reference for a continuation of R & D Project 22312 as described in the present report.

1.4 Objectives and Terms of Reference

- Development of a purpose-designed testing machine to give greater accuracy and convenience in aggregate testing applications. The existing commercially available equipment which is designed for larger specimens is insufficiently accurate and unnecessarily bulky.
- Further investigation of the size effect, correlation with uniaxial compressive strength, and relationship between irregular lump and diametral point load strength tests using a rock selected for its uniformity and homogeneity.
- Redrafting of the testing procedure and equipment description to accommodate changes made for aggregate testing.

1.5 Project Organization and Personnel

The research director for this project has been Dr. John Franklin. Douglas McLachlin, a University of Waterloo graduate student, was subcontracted to carry out the sample preparation, testing and much of the data analysis. He elected to make this his topic for a Master of Science thesis. Collaboration with the University of Waterloo has made it possible to extend the research by injection of additional funding through a Natural Sciences and Engineering Research Council grant.

Mr. J. G. Gruspier (MTC Research and Development Division) was responsible for liaison and project control. Mr. Chris Rogers (Aggregates Division) provided technical help and the rock samples to be tested. The prototype point load tester was developed in the MTC laboratories by Mr. Wayne Wagner and Mr. Tom Leung (Electronics Division), and by Mr. Bill Martin (Mechanical Engineering Division).

2. RESEARCH PROGRAM

2.1 Review

The earlier literature review of the point load strength test was extended through a computer data base search and also by collaboration with the Working Group on Point Load Strength Test Revision of the International Society for Rock Mechanics (ISRM), in which both researchers participated, one in a coordinating role. The review and full bibliography will be reported in McLachlin's thesis. In the present report we will highlight some of the more recent developments as they relate to this project.

2.2 Test Machine Development

The proposal had been to manufacture the machine at the University of Waterloo. However, because the required expertise and facilities were available at MTC, the contract was awarded with the proviso that MTC would develop the machine to our specifications.

Mark 1 to Mark 3 prototypes were developed and evaluated and the Mark 3 was used in the full scale testing program. A Mark 4 prototype, much improved, is expected to be completed by Fall 1985.

2.3 Specimen Preparation

Rock samples were selected and obtained by MTC from seven Ontario quarries to represent a range of aggregate-making rocks with a variety of petrographic types. Non-uniform and highly anisotropic materials were rejected as unsuitable. Rock formations and quarry sources were as follows:

Gull River Limestone - Elginburgh Quarry, Kingston
Coquinoid Calcarenite, Bobcaygeon Fm. - Francon Quarry, Ottawa
Oxford Dolostone - Permanent Concrete Quarry, Brockville
Guelph Dolostone - Canada Crushed Stone Quarry, Dundas
March Sandstone - Permanent Concrete Quarry, Brockville
Meta-Arkose/Granite, Grenville - Fleming Quarry, Washago
Logan Diabase - Zysco Quarry, Thunder Bay

Core specimens were drilled from the block samples at diameters of 70, 54, 39, 24, 19, 12 and 6.6 mm.

Irregular lump (aggregate) specimens were prepared from the block remnants after drilling. The remnants were broken using a sledge hammer and then crushed by MTC using their single-toggle laboratory jaw crusher. The crushed samples were screened into fractions retained on 26.5, 22.4, 19.0, 16.0, 13.2, 9.5 and 6.7 mm sieve sizes.

For uniaxial compressive strength testing, four 39 mm diameter core specimens, two of Gull River limestone and two of Guelph dolostone were cut and machined into 2:1 length:diameter cylinders within the ISRM tolerances for this test.

All specimens were stored for approximately 6 months before testing to allow them to reach a similar equilibrium moisture content.

2.4 Index Testing

Each rock sample was characterized by index tests as reported in Figs. 1, 2 and Appendix 1:

- Schmidt rebound hardness tests were performed on 70 mm core. Ten individual measurements were averaged and corrected to account for the angle of testing.
- Water contents were determined.
- Thin sections and photomicrographs were used to identify mineral composition, texture, and average grain size.

2.5 Diametral Point Load Strength Testing

Diametral testing was selected for a study of specimen size effects because the regular geometry of the core eliminated the influence of specimen shape. Tnese tests were also used as the basis for evaluating experimental scatter caused by measuring inaccuracies and specimen size variations.

A total of 487 diametral point load strength tests were performed (Fig. 3). Only cores of the four smallest diameters (6.6 to 24 mm) could be tested using the Mark 3 prototype. All others were too large to fit between the platens, so a conventional tester was used.

Some of the smallest and weakest specimens had such low strengths that the load cell could not register the load at failure. Only those tests for which failure loads could be recorded were included in the calculations and plotted on the graphs.

Some of the largest and strongest specimens also gave testing problems. The Logan diabase, an extremely strong rock, spalled severely. Only five tests were completed successfully at the maximum (54 mm) diameter. Both the Oxford and Guelph dolostones registered occasional anomalously low values when they failed along discontinuities rather than through the rock matrix. These values were discarded in the analysis.

2.6 Axial Point Load Strength Testing

Axial testing when combined with diametral testing on the same rock gives a measure of its strength anisotropy. Axial testing is also helpful when examining the correlation between point load strength and uniaxial compressive strength.

Fifteen axial point load strength tests were performed on the Gull River Limestone sample only. This rock type was chosen as being the most anisotropic of those to be tested. A series of bedding planes and stylolites ran horizontally across the core, so that the diametral test measured the strength in the weakest direction and the axial test determined the maximum strength of the rock.

2.7 Irregular Lump Point Load Strength Testing

Irregular lump testing is mandatory when only aggregate samples are available. In the present research, irregular lump testing was used as the principal method for evaluating performance of the prototype testers and also for the investigation of specimen shape effects.

A total of 735 irregular lump specimens were tested, 105 from each of the seven rock types. Fifteen specimens were tested from each of the seven size fractions. The largest specimens were 26.5 mm so that all tests were performed using the Mark 3 prototype. For each test the value of specimen width (W) was measured in addition to failure load (P) and platen-to-platen distance (D), to permit an evaluation of the method of shape correction recommended in the latest ISRM test procedure, and of simpler alternatives.

2.8 Uniaxial Compressive Strength (UCS) Testing

UCS testing was required as part of a further study of the correlation between uniaxial compressive and point load strengths. The testing was limited to two rock types when it became apparent from recently published research data (7) that uncertainties in this correlation had largely been resolved by others.

Four 39 mm diameter core specimens, two of Gull River limestone and two of Guelph dolostone were prepared, instrumented with strain gauges and then loaded to failure.

3. TEST MACHINE DESIGN AND CONSTRUCTION

3.1 Specifications

A new prototype was needed both for the research and for later routine testing by MTC. The following were established as general objectives for machine design and construction:

- To increase the sensitivity of load and displacement measurement, allowing for the extension of the test into the small size range (5 to 25 mm diameter).
- To build into the machine features that would automatically compute and if possible store test results, reducing the time required for testing and data processing.
- To improve the portability of the tester, taking advantage of the smaller than usual specimen size and therefore reduced loading requirement to develop a more compact and convenient machine.

Target specifications were drafted (Fig. 4). It was decided to use a small load frame designed to accommodate aggregate particles, an electronic load cell to measure loads directly, and an electronic displacement transducer to measure the platen separation distances. The prototype point load strength tester was developed in three separate stages, "Mark 3" being employed in the full-scale research program.

3.2 Mark 1 and 2 Prototypes

"Mark 1" had a cam loading system with a coarse adjustment screw to lower the platen. Although simple and lightweight, it could not be operated conveniently with one hand and was equipped with platens of non-standard dimensions.

"Mark 2" had a load cell to measure P up to a maximum of 15.6 kN (3500 lb), and a spring and strain gauge system to measure D. A coarse adjustment screw was used to lower the platen onto the specimen and to apply load. The maximum platen separation was approximately 50 mm. Mark 2, evaluated in a pilot point load testing project on Amabel dolostone, was found to have the following limitations:

- The load cell capacity of 15.6 kN was insufficient to measure the failure load of 50 mm diameter core specimens.

- The machine lifted off the work bench at higher loads. This was due in part to the short working base of the tester.
- The platens, constructed from ball bearings, rotated in their mounts which led to slippage of specimens with non-parallel faces.
- The platens did not move coaxially, so that when the ram was fully extended they did not make accurate contact. Lateral rigidity of the tester was also insufficient, because of the slender platen mounts.
- The electronics package was bulky and inconvenient.

3.3 Description of Mark 3 Prototype

The initial trials led to an improved Mark 3 prototype (Figs. 5 and 6) which was available by mid-November 1984 and proved satisfactory for use in the research program.

The tester had a "window" type load frame and a 28.6 mm diameter ram activated by a separate rather than an integral hydraulic hand pump. Maximum platen separation was 30 mm. Platens were machined to standard dimensions from solid steel bar rather than using ball bearings.

The platen separation (D) was measured using a linear variable displacement transducer (LVDT) mounted in the ram. The LVDT system was more robust than the strain gauge diaphragm in Mark 2, and the resolution (0.0025 mm) was also much better.

The load cell, manufactured by MTC, made use of diaphragm-mounted electric resistance strain gauges. It had a capacity of 22 kN and a resolution of about 0.111 kN over its full range. Hysteresis was examined by MTC by calibrating against a commercially available load cell, and was determined to be less than 0.5 per cent.

The proposed miniaturized electronics package was not available in time to be used with the Mark III point load tester. Instead, test measurements were processed by the assembly of components (Fig. 7 and Appendix 2). This equipment consisted of a cassette driven Motorolla MEK6800D2 microprocessor; a small filter, amplifier and A/D converter unit which replaced the much more bulky system of the Mark 2 model; and power packs to energise the transducers and operate the digital LED display. The A/D converter had screws to adjust the calibration of both the load cell and the LVDT.

Before each test it was necessary to reset the LED board and the microprocessor, and then to key in the location of the initial program step. Values of P and D were scanned every 35 microseconds and compared with those obtained from the previous scan. A load drop of 0.044 kN (10 lb) signalled the end of the test, at which time the values of maximum P and corresponding D were displayed.

3.4 Evaluation of Mark 3 Tester

Evaluation of the Mark 3 prototype was required as part of the current research program. It proved to be more sensitive than commercial alternatives and capable of measuring the point load strength of aggregate particles down to 5 mm diameter. With completion of the miniaturized electronics package now being constructed by MTC, it will be suitable for routine testing in MTC laboratories and for truck mounted field use.

The following is a summary of Mark 3 limitations and suggested improvements:

- Machine weight exceeded the target of 2 kg and that of commercial machines. The separate hydraulic pump alone weighed several kilograms. Machine dimensions greatly exceeded the target of 200 mm high by 90 mm wide.

- The tester was inconvenient to transport and to use because of its several components including the separate pump. A better pump-ram combination (a hydraulic cable cutter) was obtained from Enerpac but too late to be employed in this project.

- Testing was slow because of the procedure for resetting the microprocessor before each test, and because conversion from Imperial units and calculations of point load strength had to be done using a separate computer.

- The lower platen deformed. The original 5 mm radius became a 2 mm flat face, probably to the detriment of the test results particularly for smaller aggregate specimens. Platens in future machines should be hardened or machined from tungsten carbide to allow for long periods of use without replacement, and to conform with ISRM specifications.

- The load cell capacity of 22.2 kN, although greater than the target of 19 kN was less than half that needed to break the strongest rock types at full diameter (40.5 kN for a 54 mm diameter core of Logan Diabase). Limited loading capacity can be tolerated if the tester is to be used only for small sized aggregate. However, some form of overload protection will be needed to prevent damage to the machine and the load cell. The capacity of the load cell should more compatible with that of the machine.

- The load measuring accuracy of 0.11 kN (25 lb) was insufficient for tests on small weak specimens, and six times greater than the target. Many specimens failed at loads close to or less than the detection level of the equipment, causing a significant increase in the scatter of test results in the small size range. For example, about one out of two tests on 6.6 mm sizes of Gull River limestone were unsuccessful because of lack of instrument sensitivity. For the Calcarenite samples the ratio was approximately two out of three. Over a one hour

period, the zero load reading was observed to drift by up to +/- 0.011 kN (2.5 lb) and the 22.2 kN (5000 lb) reading by +/- 0.44 kN (100 lb).

- The peak-load-triggering logic (requiring a 10 lb drop in load) was unsatisfactory. About five per cent of tests are known to have terminated prematurely as a result of specimen slippage. Results could not be obtained for specimens failing at loads close to or less than 10 lb. Lack of a continuous load display made calibration difficult. A better method would be simply to record and display the maximum load and corresponding displacement.

- The platen clearance of only 30 mm (1.2 in), was much less than the target of 55 mm. This was a problem in the research, requiring use of a standard machine for the larger specimen sizes and twice the work in calibration. Although it will be less of a problem in routine applications, a 55 mm clearance is recommended firstly to avoid excluding some aggregate sizes, and secondly to allow the testing of conventional 54 mm (NX) core. It is permissible that testers be unable to break strong rocks at this diameter, but weaker rocks require the testing of large specimens if the results are to be sufficiently accurate.

- There was unacceptable drift in the displacement measuring system. The nominal LVDT accuracy of 0.0025 mm was well within the target of +/- 0.05 mm; however, the measured drift reached +/- 0.25 mm per two hours both with the platens closed and separated by a standard 19.1 mm, which is five times greater than the specified tolerance. Adjustments had to be made every hour to correct for zero drift, and less frequently to correct for amplification drift. These frequent adjustments are impractical in routine testing. Re-zeroing should be simpler and less frequent.

- The Mark 3 equipment displayed values of P and D in Imperial units only, and did not compute or store values of I_{s50} as had originally been planned. A "Mark 4" electonics package being constructed by MTC will be miniaturized and much more convenient, consisting of a 200 mm square by 25 mm thick board with all the necessary components to capture, process and display the values of I_{s50}, P and D in metric units. It will be able to store up to fifty separate strength values and compute the mean point load strength for the tested sample (Appendix 2).

4. ANALYSIS OF EXPERIMENTAL VARIABILITY

4.1 Method of Assessment

The variability of recorded strength data was examined independently of shape and size effects by using diametral test data and by examining means and standard deviations for each rock type at each diameter. Fig. 8 gives the mean values of P/D^2 with the 95 per cent confidence interval in brackets (expressed as a percentage of the mean). Only those diameters containing five or more results were included in this analysis.

Normality of the results was tested by examining the log P vs. log D^2 graphs (Figs. 10 to 16). The data set was found to be normally distributed about the mean strength value with the exception of occasional anomalously low values caused by sample slippage or by failure along a discontinuity.

4.2 Results

The 95 per cent confidence interval (Fig. 8) was found to systemmatically increase as the specimens became smaller, except for Logan Diabase and Guelph Dolostone which also showed an increase for larger specimens.

The absolute value of standard deviation (Fig. 17) was approximately constant for specimens larger than 39 mm but increased for smaller specimens. The one exception was Logan Diabase which had a large standard deviation at 54 mm diameter, probably the result of spalling.

One or all of the following three factors may account for the increase in scatter at smaller diameters:

- Limited equipment sensitivity, with respect to measurement of either load P or distance D, or both, in that measuring errors will be more significant when testing smaller specimens.
- Grain size effects, in that specimens are likely to be weaker and also more variable in strength as the specimen size approaches the grain diameter.
- Platen friction effects, in that smaller specimens are likely to be more influenced than larger ones by the restraining influence of platen friction. Higher strengths will be recorded if the platen is somewhat flattened than if it is an ideal "point" contact, as a result of crushing as opposed to an indirect tensile mode of fracture.

To determine the possible effects of equipment insensitivity on scatter, the Logan Diabase results (Fig. 8) may be used as an example:

D (mm)	6.6	24.0	54.0
P/D^2 (MPa)	12.3	14.8	10.4
P (kN)	0.54	8.52	30.33
Actual 95% C.I (% of Mean)	42%	17%	30%
Error caused by +0.1 kN	18%	1.2%	.3%
Error caused by +0.1 mm	3%	.8%	.4%

This comparison shows that reading errors of 0.1 kN and 0.1 mm, which may be regarded as typical for the Mark 3 tester, have a much greater influence at smaller diameters but even then do not account for more than half the scatter of data. It also confirms that the error of load measurement is much more important than than that of displacement.

To determine whether larger grained specimens gave a greater scatter, a graph of standard deviation vs. grain size (Fig. 18) may be examined. The graph shows a minor trend of increasing scatter with larger grain size. However, Oxford Dolostone, Guelph Dolostone and March Sandstone do not hold to this relationship.

It therefore appears that the third of the above three factors, namely platen friction caused by flatness or finite curvature, must account for an important part of the increased scatter at smaller sizes. Observations of the failure mode (point load or crushing) were made during the testing. For small diameter cores (6.6 mm) and also for small aggregate particles of all rock types, the area of pressure no longer approximated to a point. Columns of rock were observed to remain between the platens after failure. Failure occurred at least partially in a "crushing" mode rather than in the indirect-tensile "splitting" mode that is characteristic for true point loading. This would have had an effect on the magnitude of the results as well as on the scatter of the data.

5. ANALYSIS OF SIZE EFFECTS

5.1 Background and Objectives

A size correction needs to be applied to point load strength P/D^2 because without one, large specimens appear weaker than smaller ones of the same rock. Size correction allows one to obtain a single unique strength for any given rock irrespective of its size.

This ISRM size correction procedure extrapolates empirically the results of tests in the size range 25 - 100 mm, i.e. larger than typical aggregates, to a "standard" equivalent strength for a 50 mm specimen. There were indications that the same correction procedure might be valid for smaller sized specimens but this needed to be confirmed.

It was also necessary to determine the errors involved in this extrapolation. Such errors would represent departure from

"standard" size-strength behaviour, and would be a function of the choice of extrapolation alternative.

5.2 Standard Methods for Size Correction

The ISRM "Suggested Method" calls for results to be extrapolated to the values that would have been obtained had 50 mm specimens been tested. In the revised method for this test, based on work by Brook and others (2,3,4,7 and Appendix 3) three alternative size correction procedures are given:

- The most reliable method is to carry out diametral tests at or close to 50 mm diameter, which makes size correction unnecessary, but which is impractical if the only available specimens are smaller.

- A second method is to carry out a series of tests over a range of diameters and then plot a log-log graph of P vs. D^2. The value of $P_{(50)}$ corresponding to D^2 = 2500 mm^2 (D = 50 mm) is then obtained by extrapolation or interpolation.

- A third method is recommended if the only available specimens are of a single or a small range of diameters not near 50 mm. Experimentally (at least for tests on larger specimens) the above log-log plot has been found to be linear with a slope (n) of approximately 0.775 and m = 2(1-n) = 0.45 This allows use of a size correction (extrapolation) formula $I_{s50} = F \times I_{sD}$ where $I_{sD} = P/(D)^2$, and the "Size Correction Factor F" is given by $F = (D/50)^m$.

From the results of Brook (3), the value of m, while generally close to 0.45, can vary from 0.2 to 0.8 (n = 0.6 to 0.9) depending on the rock type, which would correspond to an error of +/- 15 per cent in determining the size-corrected point load strength of a 25 mm diameter specimen.

The first alternative evidently can not be used when testing aggregates. Our objective was to determine the errors of extrapolation inherent in applying the remaining two alternatives and which, if either, should be used for aggregate testing.

5.3 Experimental Procedure and Results

Tests on core specimens were used in this study of size-strength relationships, to eliminate shape effects that would have confused the analysis. Results for each rock type were as P/D^2 vs. D (Fig. 9) and also as log load vs. log diameter squared (Figs. 10 to 16). Log-linearity was examined, and gradient was compared with the "standard" of n = 0.775 (range 0.6 to 0.9) or m = 0.45 (range 0.2 to 0.8).

The pattern of behaviour that has been well established at least for larger specimens, is for P/D^2 to decrease with increasing diameter.

Fig. 9 shows that in the current test series this trend was reversed for specimens smaller than about 25 mm. The standard form of size correction could not therefore be expected to accurately represent these results.

This non-standard behaviour was confirmed by the log-log plots (Figs. 10 to 16) which were non-linear below 25 mm diameter. Stronger rocks showed a downward curve at the smallest diameters (e.g. Fig 15) whereas the weakest rocks (Gull River Limestone and Coquinoid Calcarenite) showed an upward curve, indicating that the recordable failure load (P) was approaching a constant value for small diameters (e.g. Fig. 11). Linear regression was used to obtain gradient "n" and exponent "m" in spite of the non-linearity, as required by the ISRM Alternative 3.

An initial analysis considered only core diameters greater than 19 mm. The Calcarenite sample had m = -0.64; all other samples had m values in the range +0.17 to +0.67. A second analysis considered all diameters. The computed values of m ranged from -1.640 to +0.276. The average, m = -0.156 (excluding the extreme of -1.640), was much lower than the commonly accepted value of 0.45. A similar plot for all the irregular-lump aggregate specimens (Fig. 19) confirmed this, giving an average value of m = -0.711 with a range from +0.623 to -1.095.

The magnitude of error in assuming m = 0.45 when in fact it may be as low as -1.6 can be seen from the following example, which assumes D = 10 mm and P/D^2 = 10 MPa:

m	F	Error
0.45	0.485	0%
0.30	0.617	27%
0.20	0.725	49%
0.10	0.851	76%
0.00	1.000	106%
-1.00	5.000	931%
-1.60	13.100	2603%

When the "m" value is in fact positive, the assumption m = 0.45 gives a corrected value which although in error by up to 106% is closer than the "raw" I_{sD} to the "true" I_{s50} value. However, when the m value is in fact negative, the correction assuming m = 0.45 is worse than useless.

5.4 Conclusions re. Size Correction

Taken at face value, the results discussed in Para. 5.3 above would indicate that the "alternative 3" standard size correction procedure (see Para. 5.2) can involve errors of up to 106% when applied to samples with positive "m" exponents, and much larger errors when the exponent is negative.

However, there are indications that the results may have been severely biased, particularly in the small size ranges, by platen

distortion and by measuring insensitivity (Paras. 3.4 and 4.2 above). The limited data reported in the literature for point load strengths of small specimens show a trend close to that for larger specimens - much closer than our present findings would indicate. We have insufficient confidence in the Mark 3 tester to believe our own results when they conflict with those of others.

For this reason, we do not report here the results of our attempts to fit non-standard (bilinear) size correction curves to the experimental data. They will be reported in McLachlin's thesis. Even if our results are later substantiated, the bilinear curve-fitting procedure is likely to be impractical for routine size-correction purposes.

We recommend the following with regard to size-correction:

- That the platen and sensitivity problems of the tester be corrected and checked to give confidence in the machine's performance when testing sizes in the range 5 to 55 mm.

- That tests be repeated on the same rock samples to check the results presented in this report.

- That in the meantime, the size correction $I_{s20} = F \times I_{sD}$ be applied, where $F = (D/20)^m$ and $m = 0.45$. This simple correction will relate all results to a "secondary standard" I_{s20} which is more relevant to aggregates than a 50 mm standard. The "true" I_{s20} value can be cheched using 19 mm core. The relationship between I_{s20} and I_{s50} can be checked later although it is of limited relevance in the aggregate testing application and will not affect ongoing use of the test.

- That for the present, aggregate point load strength testing should be mostly on particles passing a 26.5 mm and retained on a 16 mm sieve. With this precaution, errors resulting from size correction are likely to be in the order of +/- 20 per cent.

- That further research be conducted with the improved machine to establish the I_{s20} size correction for particles in the size range 6.7 to 19 mm, which is the standard range for Petrographic Number determination.

- That in the meantime, I_{s20} values can be used in conjunction with Petrographic Number determination, on an experimental basis. Specimens in the full range 6.7 through 19 mm should be tested and a log-log plot of P vs. D^2 constructed. Extrapolation should be used to determine I_{s20} as per ISRM alternative #2. This value should be compared with that computed by assuming m = 0.45 as proposed above.

6. ANALYSIS OF SHAPE EFFECTS

6.1 Background and Objectives

For diametral tests on core, only the diameter D need be considered when calculating point load strength. For tests on irregular specimens such as aggregate, however, it is necessary also to consider the shape of particle represented both by D and by the smallest width W perpendicular to the loading direction.

In early research, the influence of W was recognized and accounted for by specifying that only more or less equidimensional particles should be tested. Subsequent research showed that truly irregular (flaky) particles could also be tested to give "standard" strength values, provided that I_{s50} was calculated as P/DW rather than as P/D^2 (2). Otherwise, unrealistically high strengths would be obtained when W>>D. Note that when W=D (as for core, cubes or spheres), the strengths of core and "irregular" specimens are virtually identical. To limit errors, the new ISRM Suggested Method (6) limits testing to particles with a D/W ratio between 0.3 and 1.0. Loading is always along the shorter axis, D.

Actual measurement of W for each particle is tedious and may be avoided if the errors in ignoring any difference between W and D are regarded as acceptable. Therefore our research was directed towards answering the following questions:

- How much error is intrinsic in ignoring the particle width W, i.e. in assuming that the width is equal to the dimension D?
- Can this error be regarded as acceptable in the interests of retaining the simplicity of the testing procedure?
- Is a compromise between simplicity and accuracy possible, either by assuming that the ratio of D/W is constant for typical aggregates, or by measuring this ratio prior to testing?

6.2 Experimental Procedure and Results

Tests were carried out on crushed aggregate particles from the same samples as used for diametral testing. D and W were measured for every specimen tested. The effect of assuming W=D was investigated by comparing P/D^2 with P/DW, assuming the latter to be the "true" value for any given specimen size range.

The error intrinsic in assuming W=D was found to vary from 1 per cent to 577 per cent with an average of about 200 per cent. D/W for all 735 irregular lump tests was found to average 0.54 with a variation in the range 0.1 to 1.0 (Fig. 20).

6.3 Conclusions re. Shape Correction

Questions of shape correction, unlike those relating to size effects, were largely resolved in the current research. The following are our conclusions:

- The error in assuming W=D, typically 200 per cent and up to 577 per cent in these tests, is regarded as unacceptable and can be avoided or at least greatly reduced by a simple procedure described below.
- The expedient of measuring W for each particle greatly slows the testing and, while necessary for this research, is not recommended during routine testing.
- The assumption that D/W = 0.5 may be a sufficiently close approximation for most purposes and should permit testing without measurement of W.

Note that the result D/W = 0.5 may be valid only for certain rocks and certain crushers. When in doubt, the ratio should be checked by flakiness sieving, caliper or dial gauge comparator measurements, and adjusted if necessary. Otherwise, errors could be introduced both if the aggregate particles were unusually flaky, or unusually rounded as in the case of a natural gravel. The assumption D/W = 0.5 would result in a 67 per cent overestimate of strength for a flaky aggregate with D/W actually 0.3. The same assumption would result in a 50 per cent underestimate of strength for a well-rounded gravel with D/W = 1.

When determining the point load strength of aggregates we therefore recommend that an initial estimate be made of the flakiness ratio D/W = "R" for each sample. R may be assumed as 0.5 or, preferably, measured. I_{sD} is to be calculated not as P/D^2 but as PR/D^2 and then size-corrected as described above. A residual error of 20 per cent in the estimate of R (e.g. measured value of 0.4 c.f. actual value of 0.5) will result in an error of 20 per cent in the strength estimate, which should be acceptable for most practical purposes.

7. CORRELATION BETWEEN STRENGTH TESTS

7.1 Background and Objectives

Although there are exceptions, the results of the many types of rock strength test correlate closely with each other, giving regression coefficients usually above 0.8 and often substantially above 0.9. This points to the possibility of choosing a simple type of test to predict results of the more complex ones.

Because the point load test is simple, reproducible and inexpensive, there have been many studies to correlate I_{s50} with the more expensive uniaxial compressive strength (UCS) test which until

recently was the sole basis for rock strength classification. Several important questions have been addressed in the literature:

- Can the point load strength index be directly correlated to the uniaxial compressive strength of rock?
- What magnitude of errors might be experienced when using a standard correlation factor relating UCS to I_{s50}?
- What rock properties affect the relationship between the two tests?

As a result of their early work, Broch and Franklin (1) proposed the relationship UCS = 24 I_{s50} (r = 0.88). Departures from the simple "x 24" factor became apparent in subsequent research, as discussed below. For example, in the feasibility phase of the current R & D Project 22312 (reported in May, 1981), this factor (which will be subsequently termed "N") was found to be 16.4 for the Nelson Quarry dolostone. For this reason, it was decided to include further consideration of the relationship between UCS and I_{s50} in the present extended study.

We first reviewed the more recent literature on this topic. It became apparent that N = 24, although realistic in the majority of cases, had many exceptions. Rather than being a constant, N appears to be related to strength and also to such properties as brittleness and porosity. We decided therefore to concentrate on a review of this aspect and to limit the experimental research to just a few UCS tests.

7.2 Experimental Procedure and Results

Results of uniaxial compressive strength testing on the two selected samples are presented in Fig. 21.

The Guelph dolostone gave a ratio N = 23, which is very close to the expected value of N = 24 for stronger rock types. The Gull River limestone was the most anisotropic rock type in the study, having a strength anisotropy ratio I_{a50} of 1.29. We followed the usual procedure of comparing the maximum point load strength (perpendicular to bedding) with UCS when attempting a correlation. This gave a ratio N = 56.8, much greater than expected.

7.3 Review of Correlations

Pells (8) found that use of N = 24 gave errors of more than 20 per cent in predicting UCS for several rock types, and an overestimate by more than 100 per cent in the case of one dolerite sample. Van Heerden (10) reports that N is usually between 20 and 25 when NX core is used, although in his full program which involved 1000 rock specimens, he found N to vary between 15 and 50.

Rutka (9) investigated the effects of porosity, texture and mineral

composition on the N values. She concluded that coarse grained rocks and ones with a high quartz content have higher N values than microcrystalline, fine grained and low-quartz types.

Johnston (7) used an empirical method of curve fitting to examine the ratio of UCS to tensile strength for a range of rock types having varying strengths. He reports the relationship $T = 0.8\ I_{s50}$, between direct tensile strength T and point load strength. He concludes that N = 24 is probably quite reasonable for rocks having a UCS of approximately 100 MPa. However, some tests performed on rocks of lower strength gave N values of less than 12. He has proposed a relationship between N and absolute strength that appears a reasonable fit to the data over a wide range of strength values.

7.4 Conclusions re. UCS Correlation

The following conclusions relating to the correlation between UCS and I_{s50} and the prediction of one from the other represent not only our own views, but also a concensus between the researchers cited above, who contributed to the recent ISRM Working Group on Point Load Test Revision. These views are reflected by the wording of the revised Suggested Method (6).

- The value N = 24 is probably the best "average" available and in most cases will result in errors of less than 20 per cent when used to predict UCS from I_{s50}.
- There are, however, many exceptions and N can vary from 15 to over 50 (e.g. the Guelph Dolostone, N = 56.8)
- With increasing acceptance of the point load strength test, there is no longer a pressing need to predict UCS values. The point load strength values themselves should be used directly for purposes of rock strength classification.
- Variations in N reflect real variations in the ratio of compressive to tensile strength that occur as a result of differences in mineral composition and texture. The point load test is an "indirect tensile" test. Tensile strength is just as relevent as compressive strength in most practical applications of rock classification, and more relevant in certain applications such as to percussive drilling and the prediction of aggregate durability.

There remains some uncertainty in which physical and mineralogical characteristics affect the N value, and also in how the N concept should best be applied to the case of anisotropic rock.

8. TESTING METHOD

8.1 Review of Objectives

The terms of reference as stated earlier in this report included "redrafting of the testing procedure and equipment description to accommodate changes made in relation to aggregate testing".

During the course of this research we have contributed to revision of the ISRM Suggested Method which, as a result, includes provisions for the testing of aggregates. It is in our opinion of little benefit to go much further than this at the present time. The expected improvements in the Mark 3 tester will, for example, allow the proposed size correction procedures to be checked, and will permit a reevaluation of experimental scatter and therefore the required numbers of test specimens per sample.

Material pertinent to the present objective and to a further updating of the Suggested Method is given throughout this report under the appropriate headings. The following are additional recommendations as they affect the specific aggregate testing application. In the meantime, we recommend that the ISRM Suggested Method be used in its present form (Appendix 3).

8.2 Advantages of the Point Load Test for Aggregate Evaluation

Direct measurement of the strength of individual aggregate particles appears to be useful. Alternatives such as the Los Angeles Abrasion and Aggregate Crushing Value tests measure the bulk characteristics of particles and can not discriminate, for example, between the different strengths of different rock-type or size fractions. They are often slower and less reproducible than the point load test, which in the present program of research was found to give a scatter of typically +/- 20 to 50 per cent of the mean value; we believe that this scatter can be substantially reduced by improvements to the tester. It should be possible to test a sample of 15 to 20 particles in less than five minutes.

A further reason for selecting point load strength as an aggregate quality criterion is that it is rapidly becoming the standard in other applications. There appears to be no fundamental reason why aggregate strengths should be measured differently from the strengths of rocks in general.

There is a limit to the number of different tests that can practically be performed for quality control. Inclusion of an additional test will probably lead eventually to one or more being dropped. No test can be dropped until a suitable replacement has been found. The point load test has yet to be fully proven in the aggregate testing application but appears sufficiently promising to be given a further and more practically-oriented evaluation.

8.3 Sample Preparation

The sample should be prepared by sieving either crushed or natural gravel aggregates. Sizes in the range 16 to 26.5 mm are recommended initially for the evaluation of accurate I_{s20} values, but a range from 6.7 to 19 mm can also be tested to correspond with current procedures for Petrographic Number determination.

Size fractions in either of these ranges may be lumped together or kept separate as "sub-samples". Each sub-sample may if required be further separated into rock types according to the Petrographic Number procedure but without differentiating between "hard" or "soft", "weathered" or "unweathered" types, since this aspect will be determined quantitatively by testing.

The numbers of tests to be performed on each sub-sample depends on the required degree of accuracy. Improvements to the tester would make obsolete any present attempt to establish a relationship between numbers of tests and accuracy. It appears, however, that when sufficient fragments are available, there should be at least ten and not more than twenty tests per sub-sample. Sub-samples containing fewer fragments (for example, of a deleterious rock type) should be tested in spite of any accuracy limitations.

8.4 Testing and Data Processing

The flakiness (D/W ratio) of each sub-sample should first be esimated or measured. Use of calipers or a dial gauge comparator is likely to be faster and more accurate than flakiness sieving particularly if different fractions have different values.

The sub-sample should then be tested to determine an average value for P/D^2. This is then to be multiplied by the appropriate D/W to obtain the average $P/DW = I_{sD}$ value.

I_{sD} for several different size fractions of the same rock type may then be plotted against the average D for each fraction and the result extrapolated to determine a 20 mm value (I_{s20}). The same can be achieved by plotting log P against log D^2 but this may be a little more tedious. For comparison, or as an alternative, I_{s20} may be calculated approximately as $I_{sD} \times (D/20)^{0.45}$.

8.5 Application of Results

The I_{s20} value should be termed the "20 mm point load strength" to avoid confusion with the standard I_{s50}. It may be used alone as a measure of strength for the sub-sample, or may be plotted against D to show the variation in strengths of different fractions. Smaller fractions of the same aggregate are likely to be weaker in most cases. The strengths and petrographic types might be combined to give an overall modified Petrographic Number, although whether and how this might be done has yet to be investigated.

Miniaturization of the tester is not essential in MTC applications; also the cost and time required for full "commercialization" are unlikely to be justified in terms of MTC objectives and budgets. Commercial production, however, would make the tester available not only to MTC but also to those laboratories whose work involves compliance with MTC specifications. A test is of limited value if only a few testers are in existence. We therefore suggest that MTC encourage and assist in development of the prototype beyond the present stage, by commercial manufacturers and with external funding. We intend to apply for Federal funding with this goal in mind.

9. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

The following is a summary of the main conclusions given in the body of the report:

- The point load test is a convenient method for measuring the strengths of aggregate particles. Some 15 to 20 particles can be tested in less than five minutes to give a strength value accurate to about +/- 20 to 50 per cent of the mean. This accuracy can be improved.

- The Mark 3 tester fell short of target requirements. It had insufficient sensitivity, clearance and load cell capacity. The maximum load recording method was unreliable. Drift was too great, and the required adjustments too frequent and inconvenient. The platens were too soft. The equipment had too many components and was too bulky. However, the tester was an improvement on commercial machines at least for purposes of this research. It is being modified to correct many of the deficiencies.

- The scatter of results generally increased at smaller specimen sizes. This is explained mostly by measuring inaccuracies, and in part by platen flattening and friction which caused a compressive type of failure in some of the smaller specimens.

- Size-strength effects were dissimilar from those reported in the literature for larger, and occasionally smaller sizes. This may be the result of measuring and platen friction inaccuracies but should be checked using an improved tester.

- For the time being we recommend size correction to a standard 20 mm diameter, using $I_{s20} = I_{sD} \times (D/20)^{0.45}$. The result may be checked by plotting I_{sD} against D or log P against log D^2 and then extrapolating to 20 mm.

- We further recommend testing sizes in the range 16 to 26.5 mm for the most reliable measurements of I_{s20}, although it should also be possible to test a range from 6.7 to 19 mm for compatability with current procedures for Petrographic Number determination.

- Shape effects were found to be significant, giving errors of typically 200 and up to 500 per cent if the width W of a particle were assumed equal to its smallest dimension D. These could be easily overcome, making use of the result that for these tests, D/W was close to 0.5. D/W should be estimated or measured to the nearest 20 per cent for a similar error in strength estimation. It is not necessary or advisable to measure W for each particle.

- The ratio N of uniaxial compressive to point load strengths, reviewed primarily from recent reports in the literature, was found to be close to the commonly accepted value of 24 in most cases, but could often assume values in the range 15 to over 50. It is becoming more common to use point load strength directly for rock classification purposes; prediction of UCS is less important than it used to be.

- The modified ISRM Suggested Method should be used for point load testing, with modifications to size and shape correction procedures as recommended in this report. Aggregate samples should first be separated into size and (optionally) rock-type fractions. The strength testing procedure may be used on its own or as an adjunct to Petrographic Number determination.

- We recommend that after improvement of the tester, the procedure be employed by MTC on a limited experimental basis. The first objective should be to check the accuracy of results given in this report, particularly for the smaller size fractions. The size correction procedure should then be reevaluated, and consideration given as to how this test might best be employed in routine quality control work.

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Sample	Schmidt hardness	W. C. %	Is50 MPa
Oxford Dolostone	45.5	0.07	7.6
Guelph Dolostone	37.0	0.04	6.3
March Sandstone	50.0	0.04	7.5
Meta-Arkose	57.0	0.03	7.3
Logan Diabase	49.5	0.12	10.7
Gull River Limestone	44.0	0.03	2.4
Coquinoid Calcarenite	50.0	0.05	4.1

Fig. 1: Index Properties of Rock Samples

	Diam. (mu)	Description
Oxford Dolostone	65 - 75	Minor quartz grains (10%) in calcite/carbonate matrix.
Guelph Dolostone	70	Very fine grained dolomite.
March Sandstone	200	Subrounded, strained quartz grains (25%) in a calcite matrix.
Meta-Arkose	450 - 500	Microcline and quartz crystals with fine Fe dusting. Minor chlorite and orthoclase (interlocking grains).
Logan Diabase	500 - 600	Plagioclase and pyroxene crystals, altered plagioclase (ceresite?)
Gull River Limestone	70	Very fine grained calcite matrix with stylolites and occassional quartz grains.
Coquinoid Calcarenite	300	Noticable glide twinning on calcite crystals, highly altered and strained. Minor Fe alteration (fossils).

Fig. 2: Mineralogic Characteristics of Rock Samples

	NAME	DATE	franklin geotechnical engineering	
Drawn By	Doug McLachlin	24 April '85		
Checked By			PROJECT: G335.1	FIGURE: 1 & 2
Revisions				

Sample	Diameters (mm) 6.6	12	19	24	39	54	70
Oxford Dolostone	9	11	14	12	9	13	4
Guelph Dolostone	7	11	11	32	12	5	7
March Sandstone	8	13	16	16	11	10	8
Meta-Arkose	3	16	12	11	12	9	-
Logan Diabase	13	15	12	11	9	5	-
Gull River Limestone	3	4	12	10	11	11	10
Coquinoid Calcarenite	1	12	13	13	10	10	-

Fig. 3: Numbers of Diametral Tests at each Diameter

Overall Requirements

Tester weight - not to exceed 2 kg (portable)
Tester size - not to exceed 200 mm high x 90 mm wide
Robustness - can be dropped without damage
Convenience - easy operation, minimum protrusions etc.

Specimen sizes and strengths

Max specimen - core 55 mm dia and any length
Min specimen - 5 mm dia piece
Max strength testable at 35 mm - 15 MPa
Min strength testable - 0.1 MPa

Loading Requirements

Max applicable load - 19 kN
Min applicable load - 0.0075 kN (1.69 lb)
Ram travel 55 mm (2.165 in)
One handed load application
Easy ram retraction - (by hand or spring)
Fixed clearance - (no coarse adjustment)
Platens standard, 60o cone, 5 mm rad. hardened
Ram friction etc. less than 0.005 kN (1.12 lb)

Load P measurement

Electronic
Max load 19 kN
Min load 0.005 kN (1.12 lb)
Accuracy overall - +0.005 kN (1.12 lb)
Register and retain max load in test

Distance D measurement

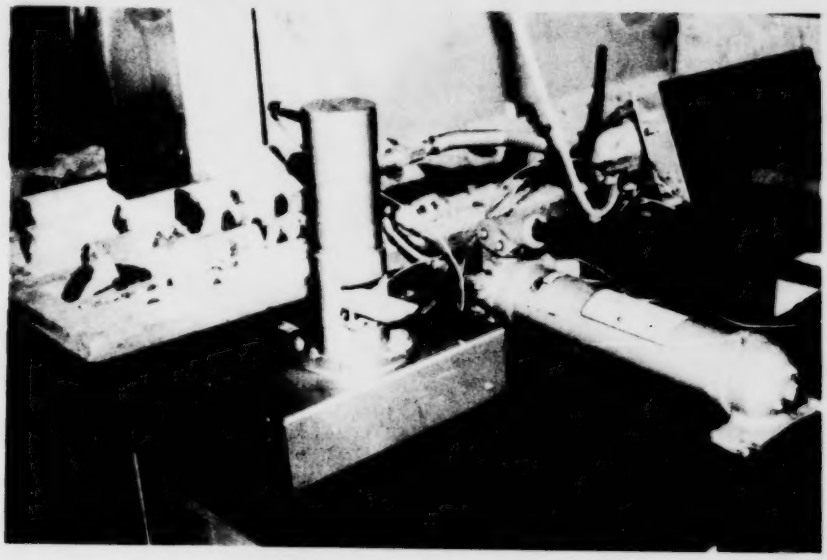
Electronic
Max range 0 - 55 mm platen-to-platen
Accuracy - +0.05 mm overall (0.1% full scale)
Register and record D at instant of maximum load

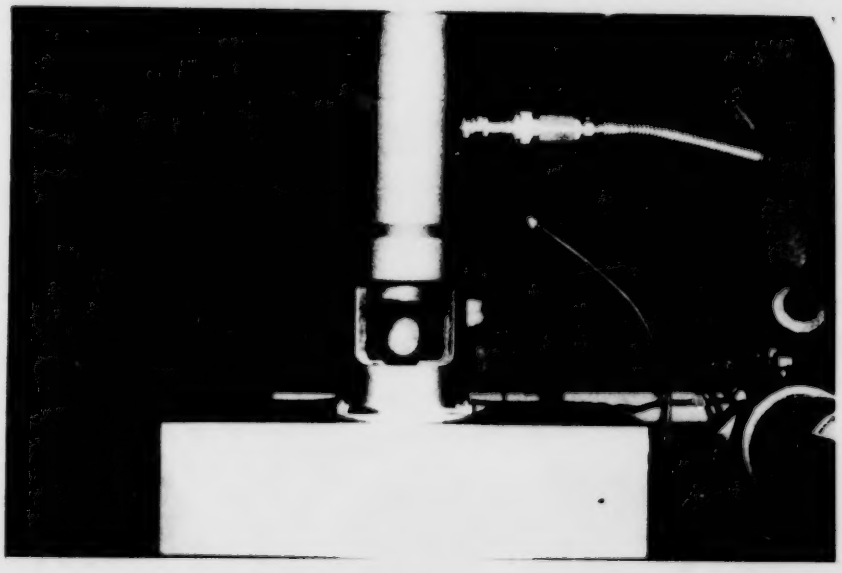
Computation and display

Compute max load P (kN) and display
Compute distance D platen-to-platen and display
Compute P/D2 and optional display
Compute I_{s50} = f(P/D2, P, D) and display digitally

Fig. 4: Point Load Tester Specifications

	NAME	DATE		franklin geotechnical engineering	
Drawn By	Doug Mackin	29 April 85			
Checked By				PROJECT: G335.1	FIGURE: 3 & 4
Revisions					





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Revisions					

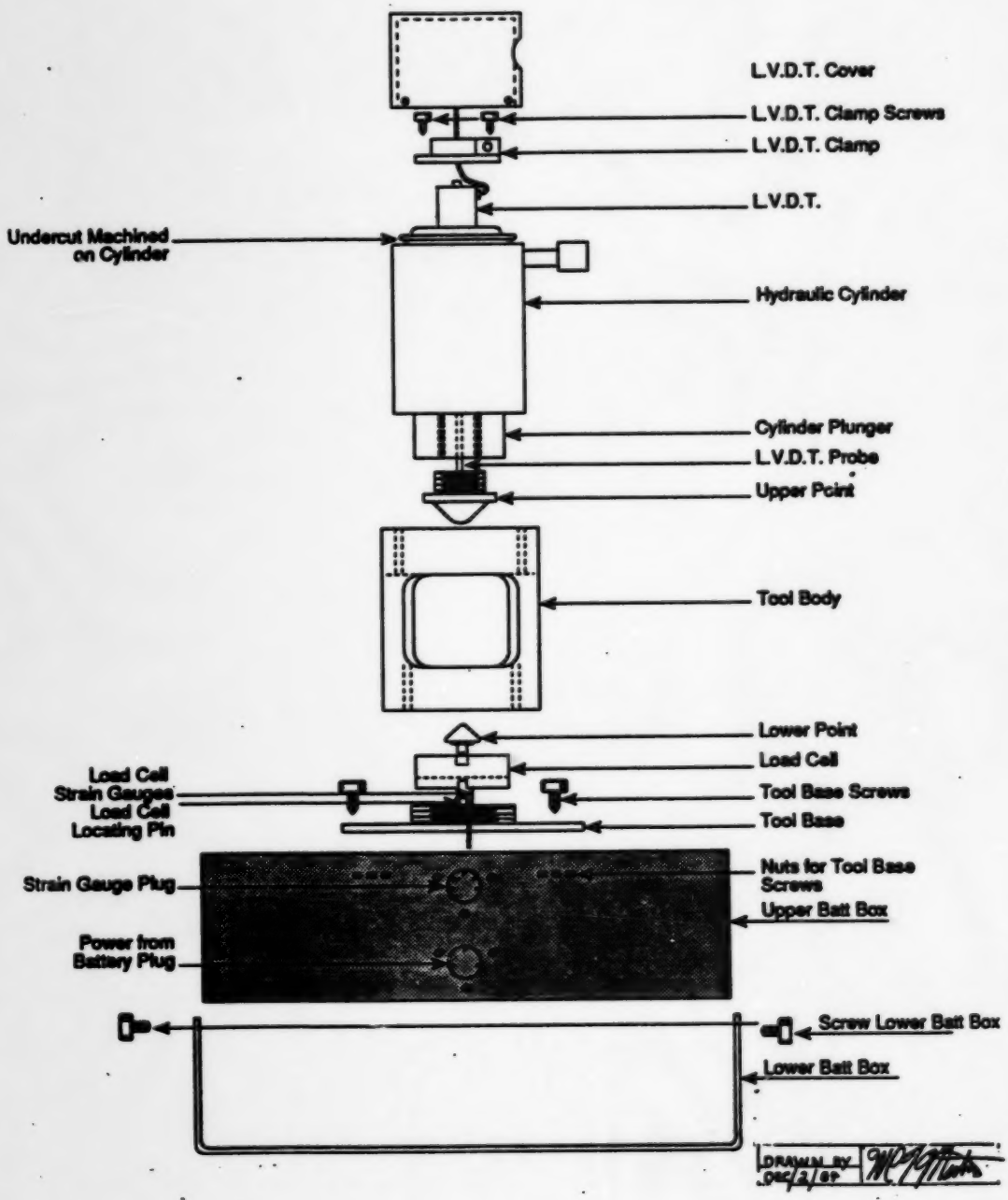
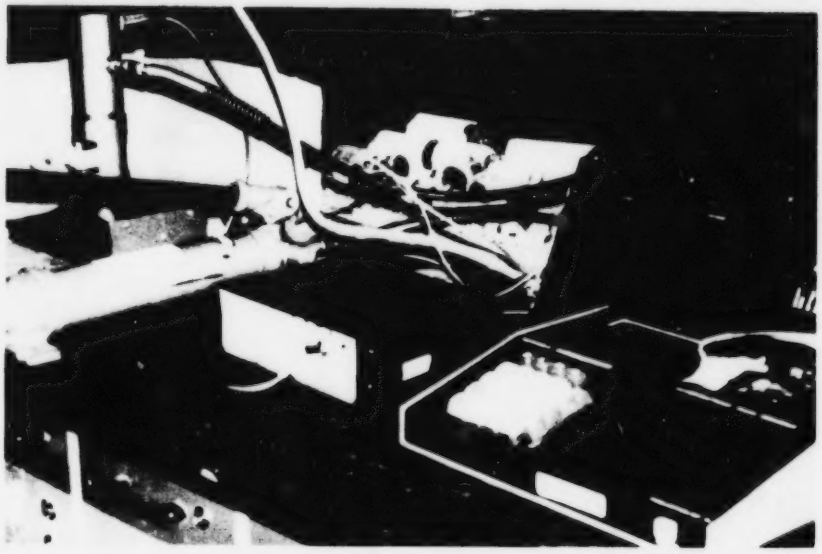
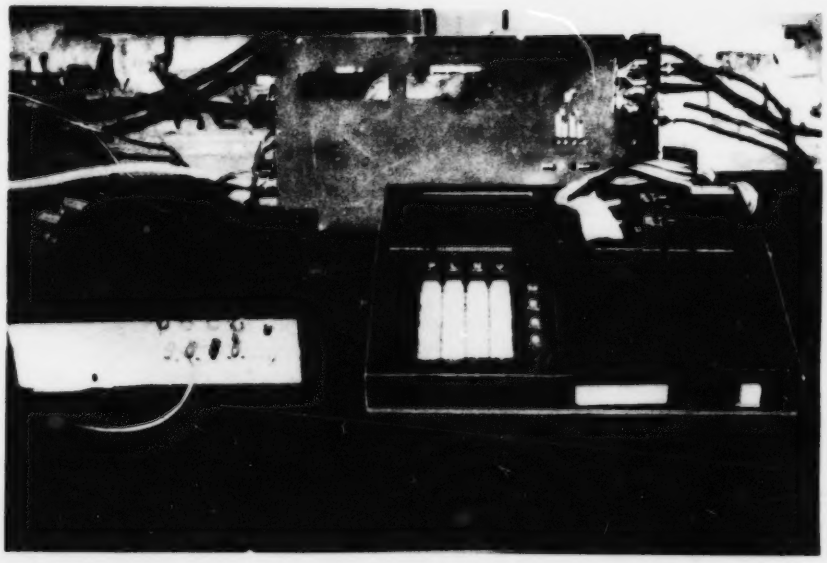


Fig. 6: Mark 3 Tester - Assembly Drawing
(prepared by Mr. W. Martin, M.T.C.)

	NAME	DATE		franklin geotechnical engineering	
Drawn By					
Checked By					
Revisions					
				PROJECT: G335.1	FIGURE: 6





	NAME	DATE
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Revisions		

franklin geotechnical engineering

PROJECT:	FIGURE:

Sample	Diameters (mm) 6.6	12	19	24	39	54	70
Oxford Dolostone	13.8 (30)	12.1 (25)	12.8 (8)	13.5 (9)	9.5 (9)	7.3 (8)	-
Guelph Dolostone	2.8 (37)	2.7 (35)	3.5 (34)	6.6 (16)	6.3 (13)	6.1 (9)	4.6 (24)
March Sandstone	4.1 (26)	7.1 (25)	7.4 (19)	9.0 (19)	8.1 (11)	7.3 (8)	5.9 (20)
Meta-Arkose	-	8.2 (19)	8.4 (20)	11.6 (8)	8.9 (7)	7.1 (11)	-
Logan Diabase	12.3 (42)	18.0 (23)	17.9 (10)	14.8 (17)	11.9 (9)	10.4 (30)	-
Gull River Limestone	-	-	0.2 (45)	0.2 (35)	2.9 (26)	2.3 (21)	2.0 (14)
Coquinoid Calcarenite	-	2.7 (30)	2.5 (33)	2.5 (21)	4.7 (15)	3.7 (7)	-

Fig. 8: Results - Diametral Point Load Strength
(Numbers in brackets are 95 per cent confidence interval expressed as percentage of the mean)

	NAME	DATE		franklin geotechnical engineering	
Drawn By	Doug McCall	24 April 85			
Checked By					
Revisions				PROJECT: G335.1	FIGURE: 8

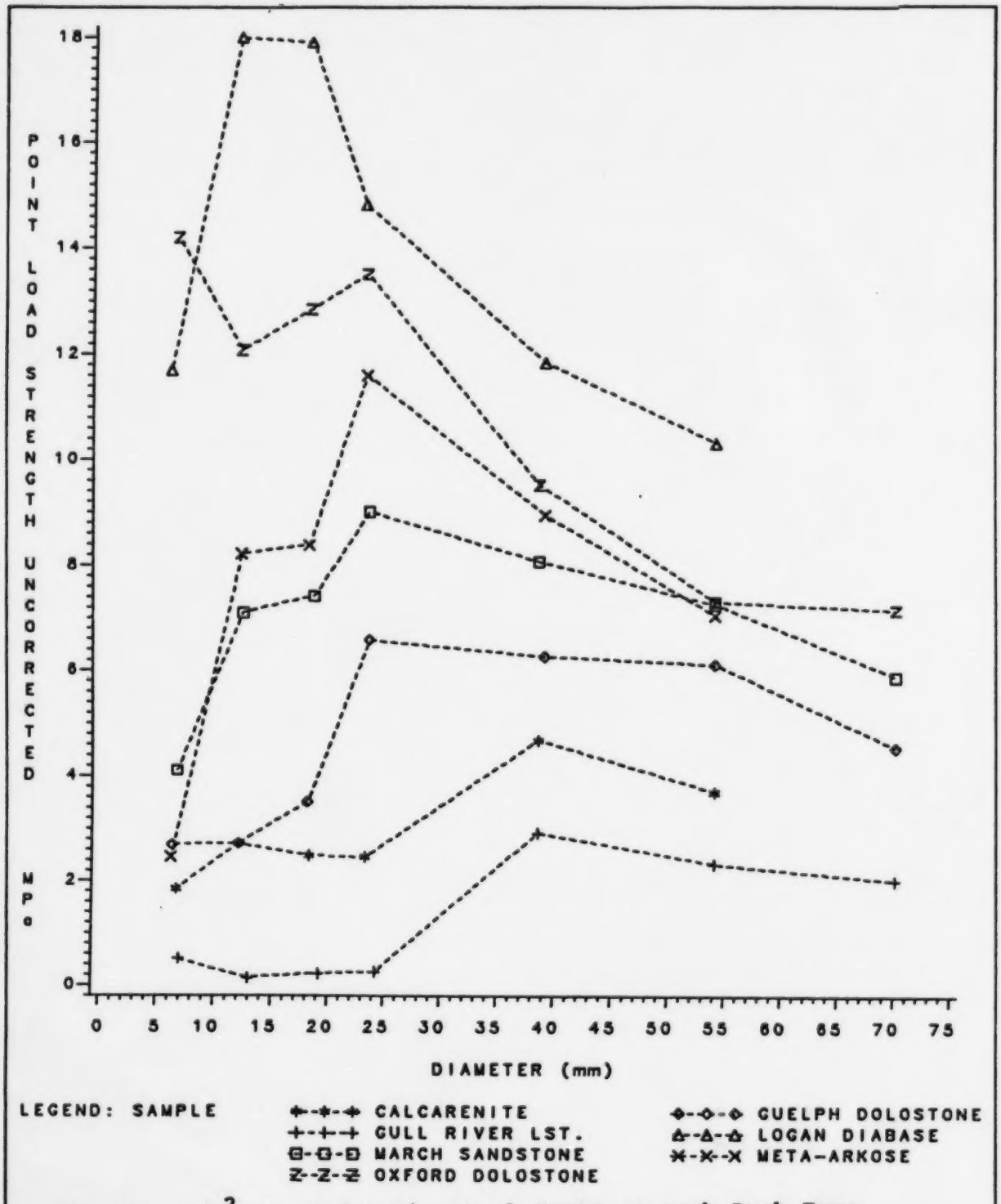


Fig. 9: P/D^2 vs. D for Diametral Tests on each Rock Type

	NAME	DATE		franklin geotechnical engineering	
Drawn By	Doug McLeod	24 April 85			
Checked By				PROJECT: G335.1	FIGURE: 9
Revisions					

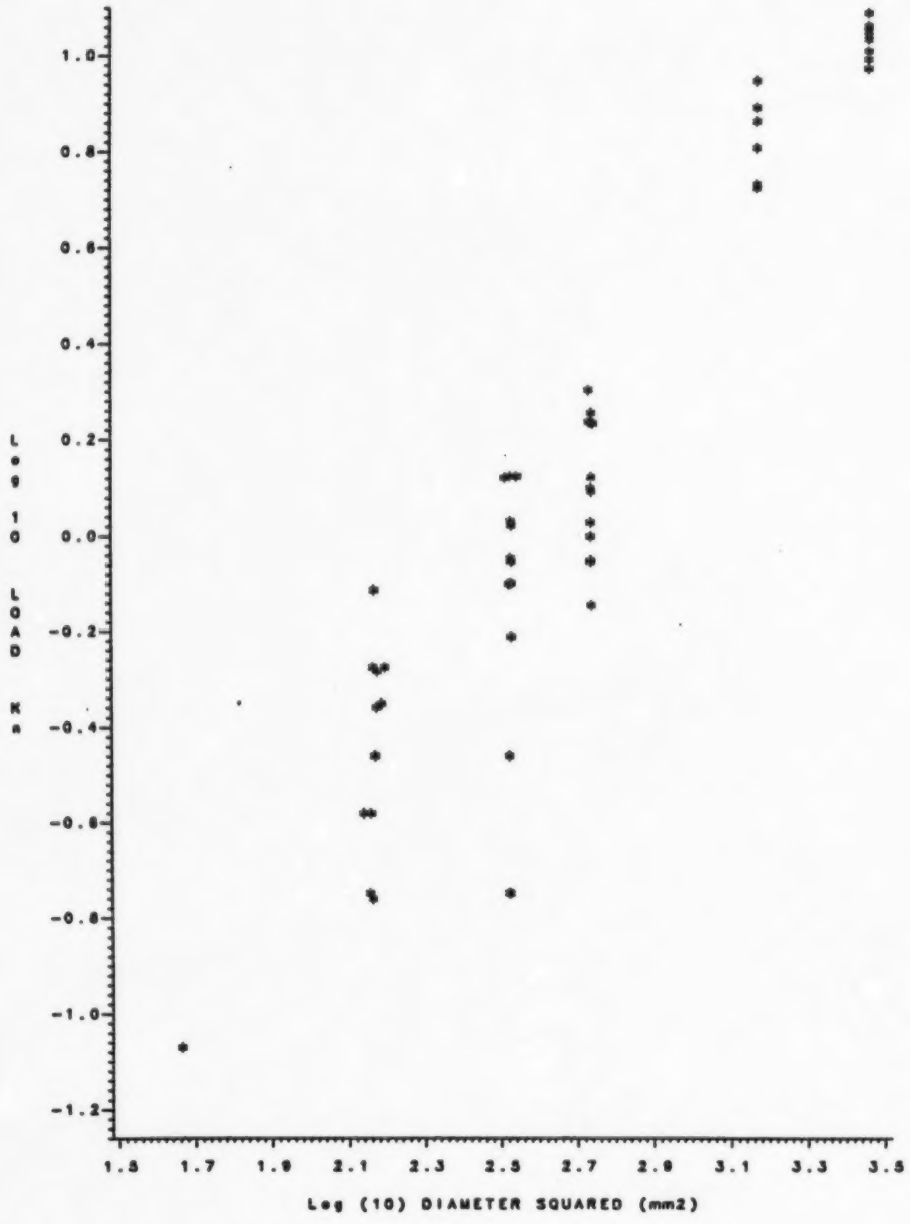


Fig. 10: Log Load vs. Log Diameter Squared Diametral Tests on Calcarenite

	NAME	DATE		franklin geotechnical engineering	
Drawn By	Doug McLachlin	24 April '85			
Checked By				PROJECT: G335.1	FIGURE: 10
Revisions					

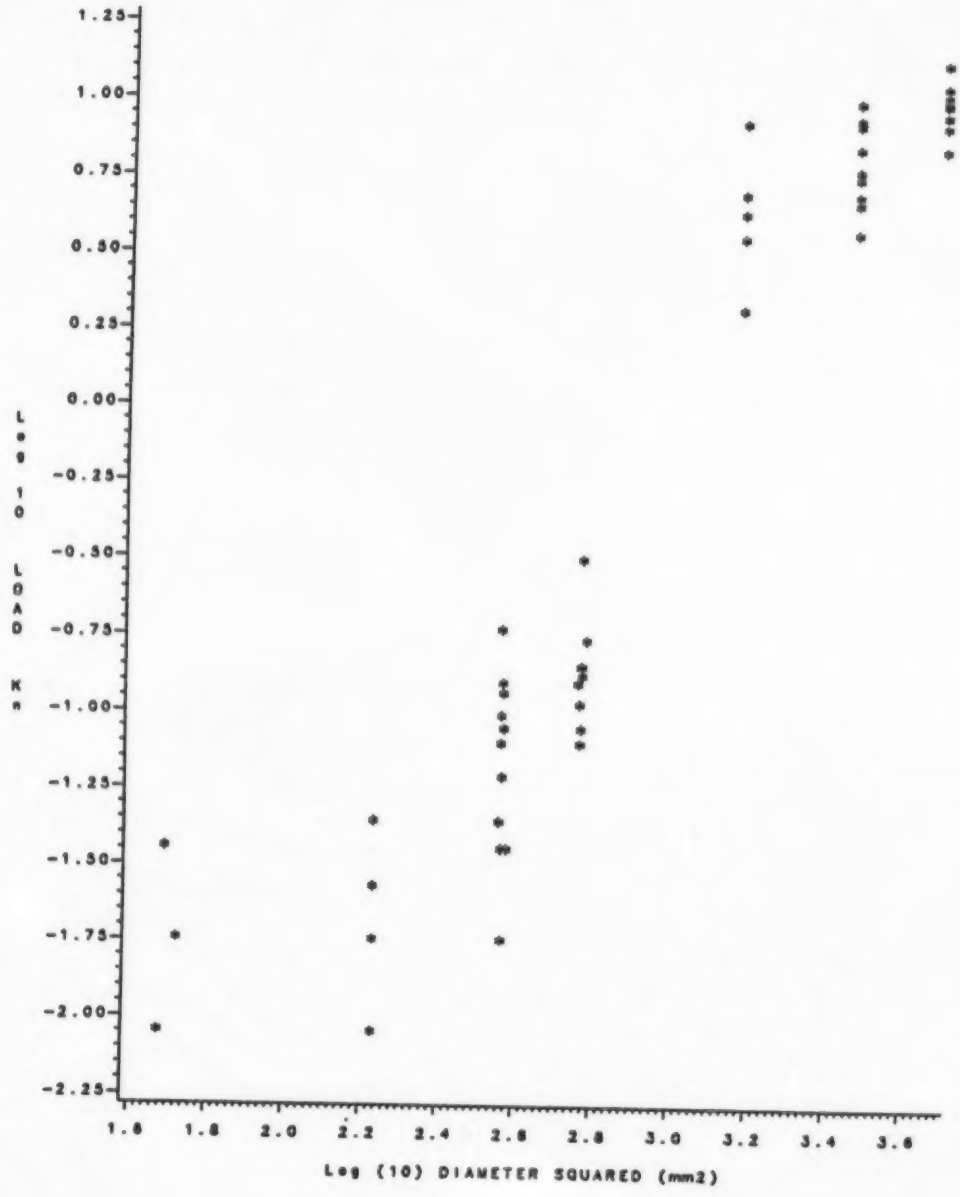


Fig. 11: Log Load vs. Log Diameter Squared
Diametral Tests on Gull River Limestone

	NAME	DATE		franklin geotechnical engineering	
Drawn By	Doug McLeod	24 April '85			
Checked By				PROJECT: G335.1	FIGURE: 11
Revisions					

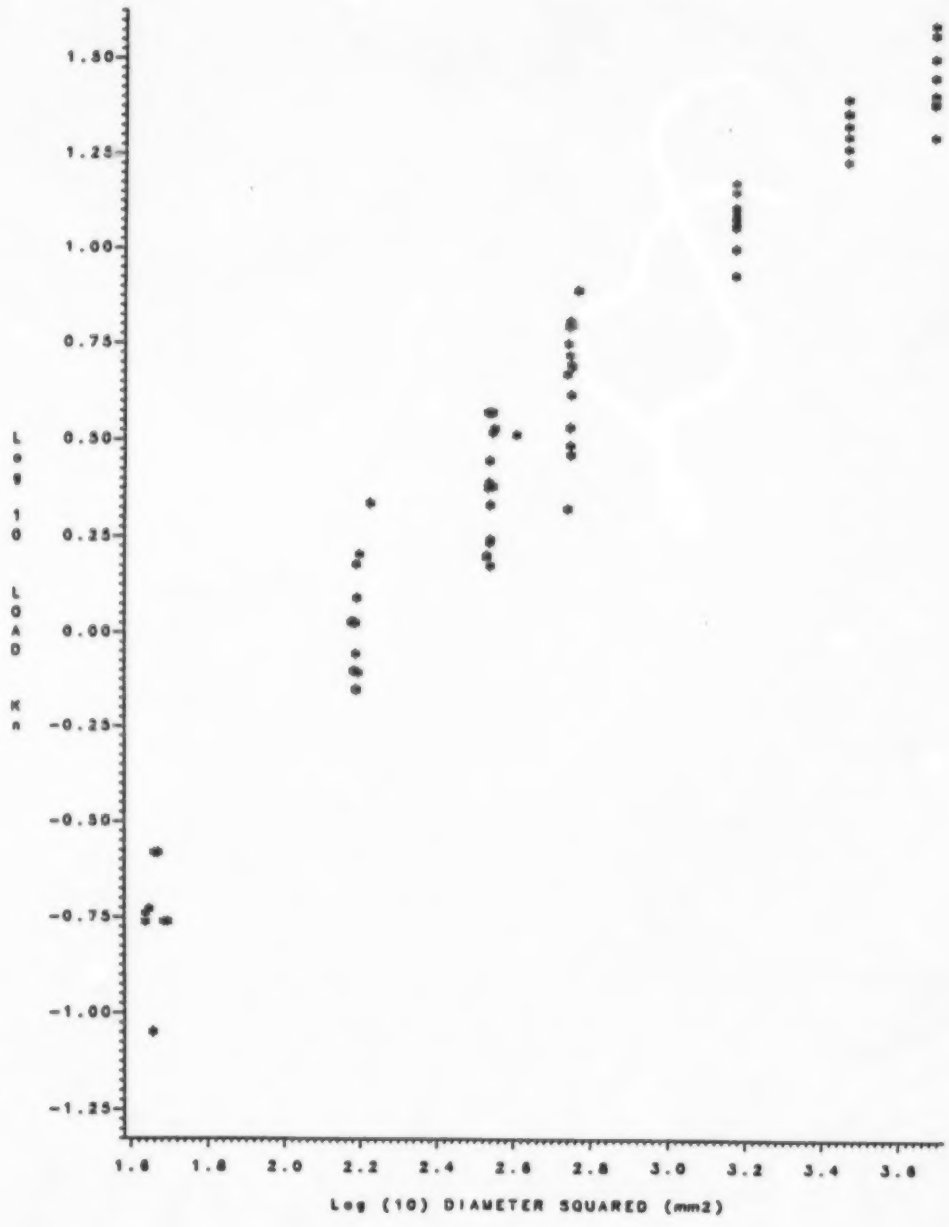


Fig. 12: Log Load vs. Log Diameter Squared
Diametral Tests on March Sandstone

	NAME	DATE		franklin geotechnical engineering	
Drawn By	Doug McLeod	24April85			
Checked By				PROJECT: G335.1	FIGURE: 12
Revisions					

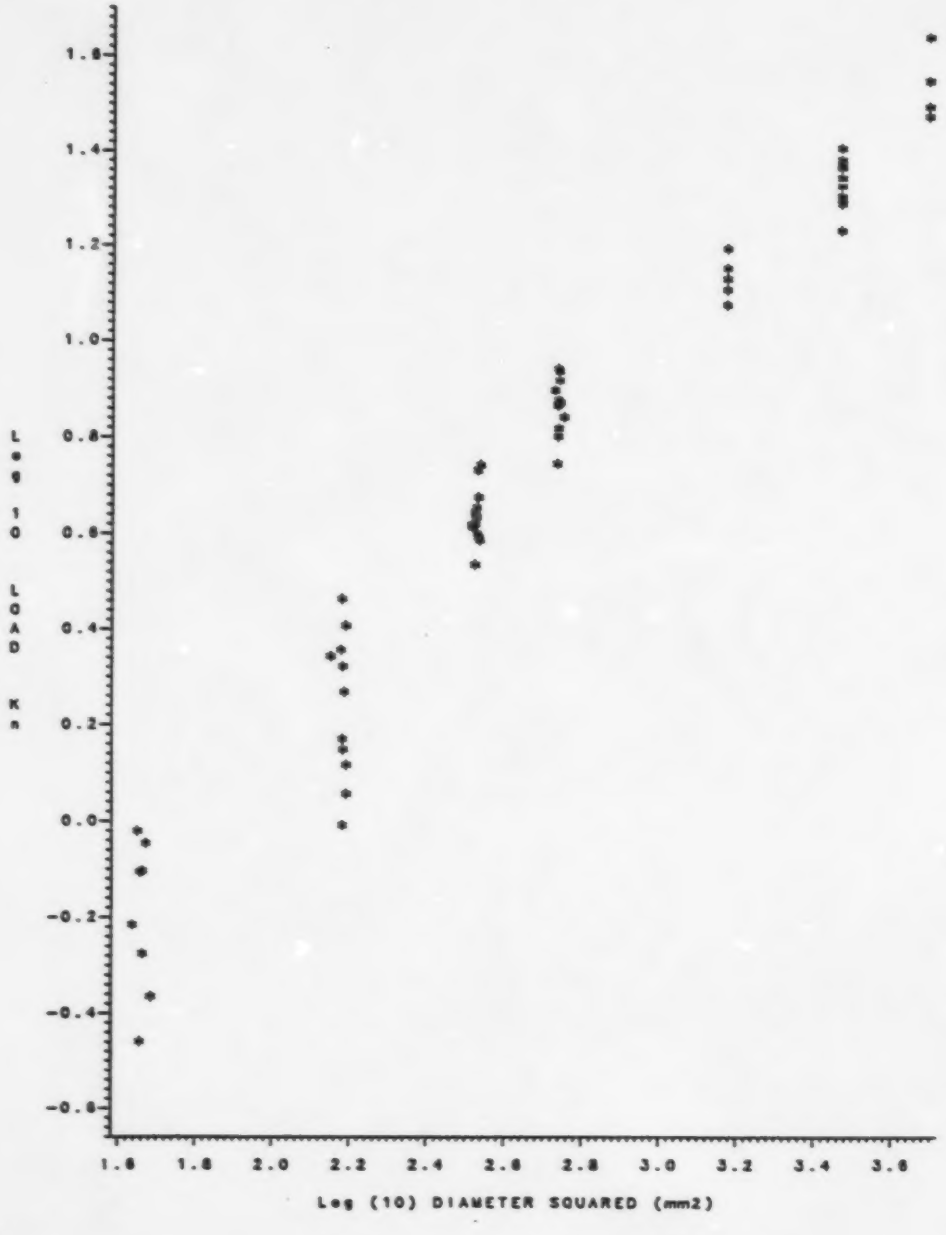


Fig. 13: Log Load vs. Log Diameter Squared
Diametral Tests on Oxford Dolostone

	NAME	DATE		franklin geotechnical engineering	
Drawn By	Doug McKechnie	24 April 85			
Checked By				PROJECT: G335.1	FIGURE: 13
Revisions					

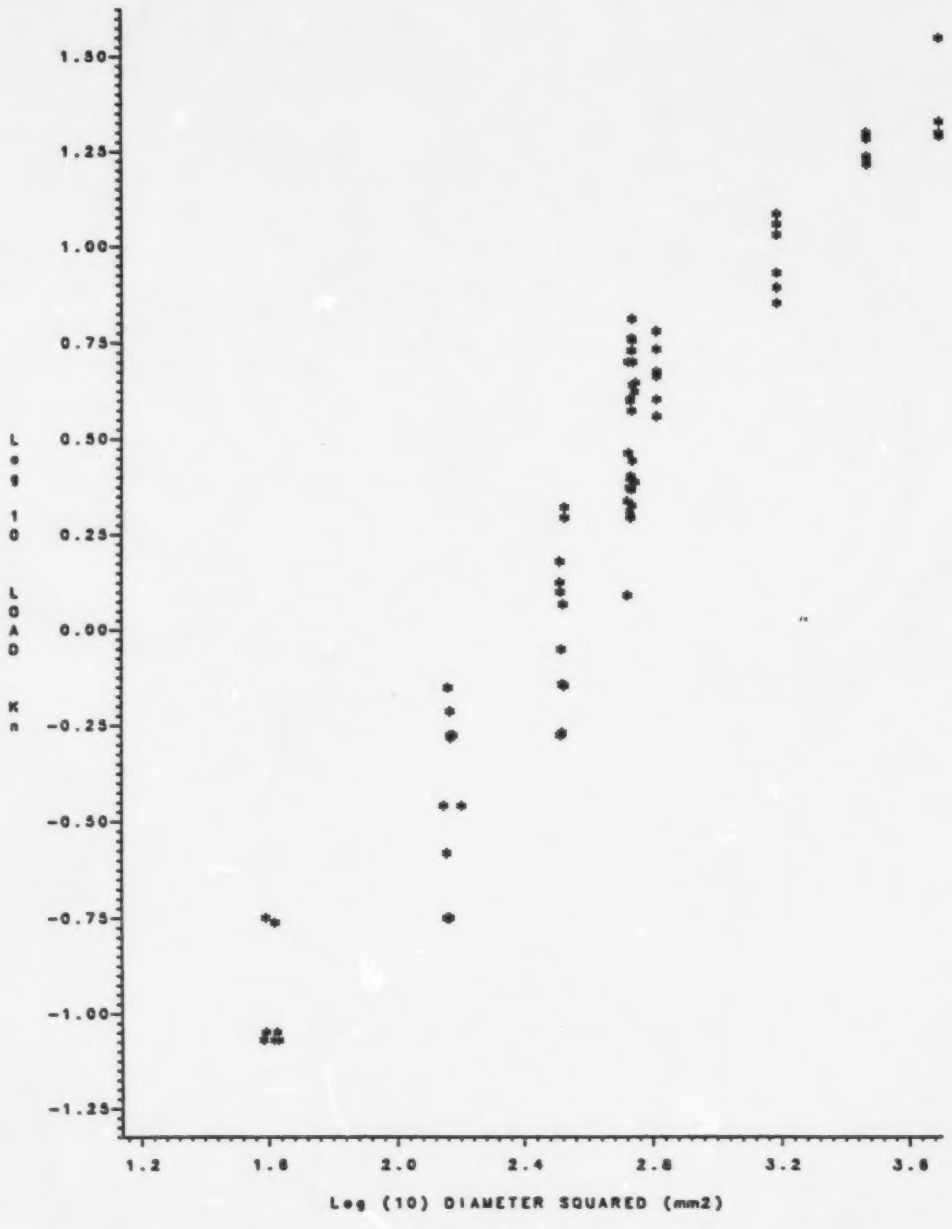


Fig. 14: Log Load vs. Log Diameter Squared
Diametral Tests on Guelph Dolostone

	NAME	DATE		franklin geotechnical engineering	
Drawn By	Doug MacNeil	24 April 85			
Checked By				PROJECT: G335.1	FIGURE: 14
Revisions					

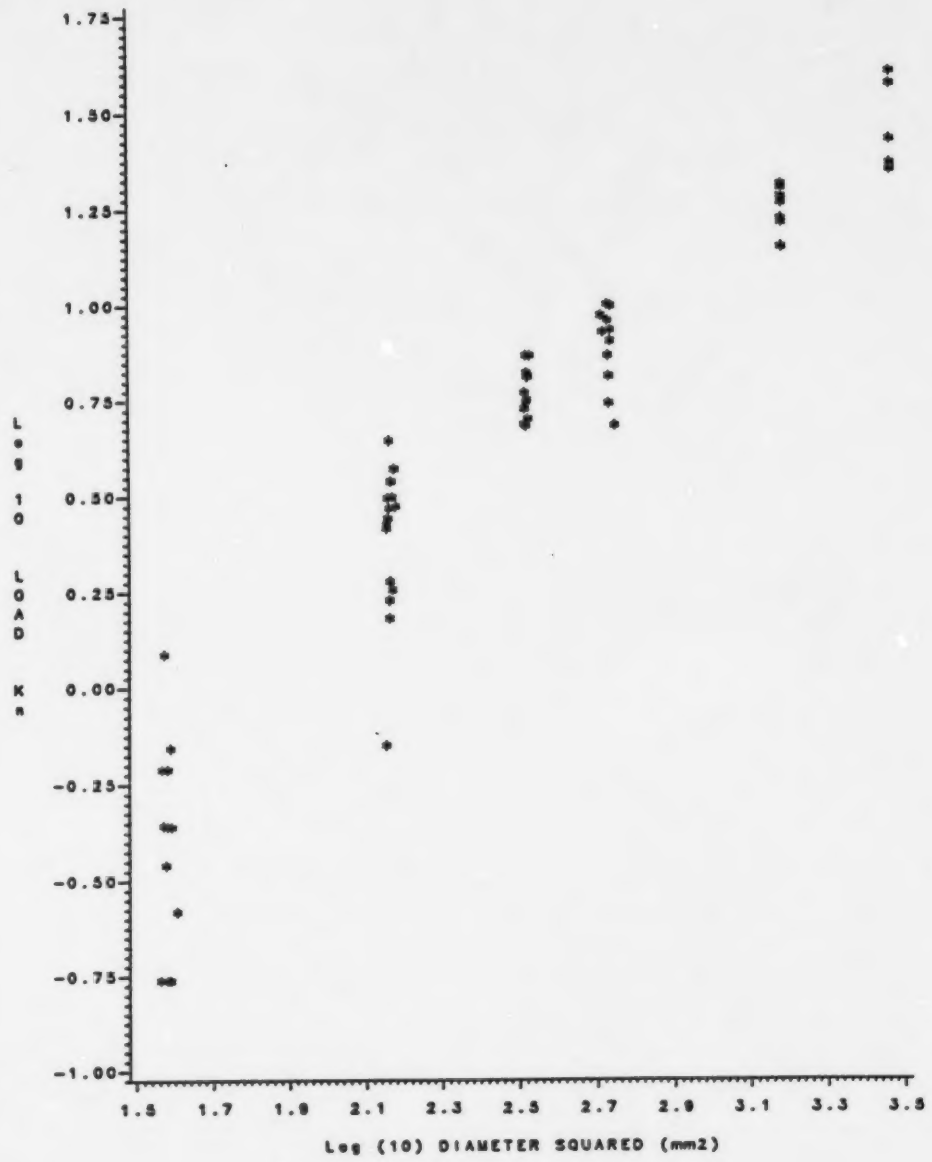


Fig. 15: Log Load vs. Log Diameter Squared
Diametral Tests on Logan Diabase

	NAME	DATE		franklin geotechnical engineering	
Drawn By	Doug McCall	24 April '85			
Checked By				PROJECT: G335.1	FIGURE: 15
Revisions					

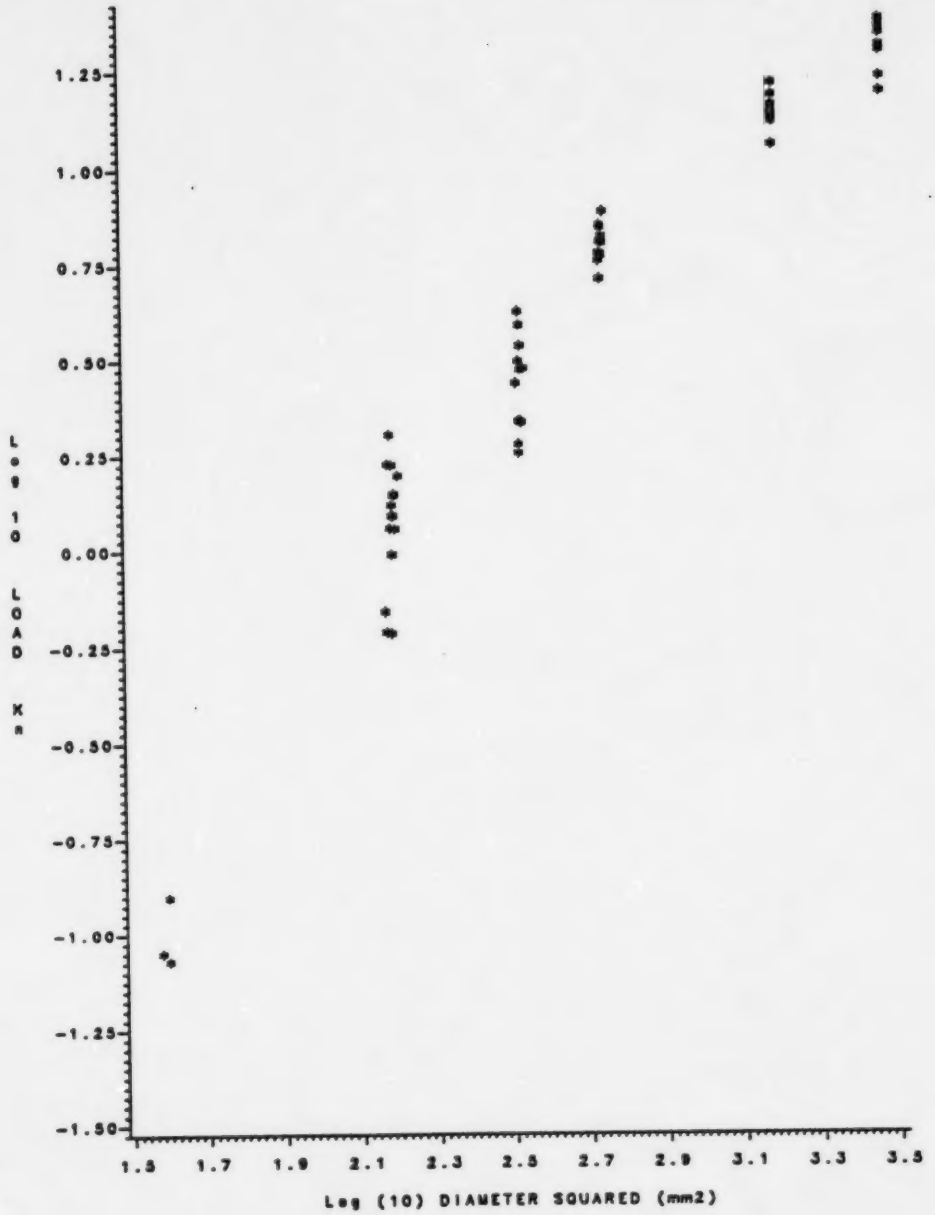


Fig. 16: Log Load vs. Log Diameter Squared
Diametral Tests on Meta-Arkose

	NAME	DATE		franklin geotechnical engineering	
Drawn By	Doug McEachern	24 April 85			
Checked By				PROJECT: G335.1	FIGURE: 16
Revisions					

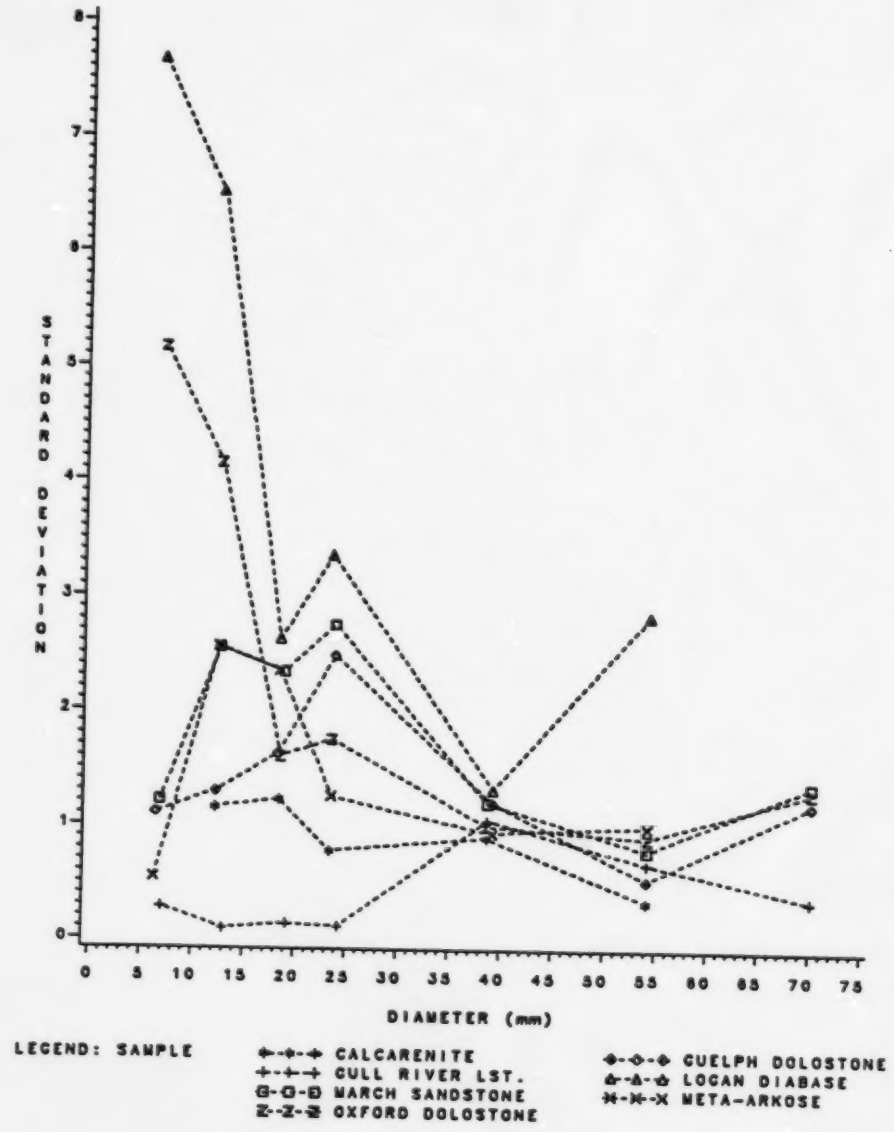


Fig. 17: Standard Deviation of Point Load Strength vs. Diameter for all Diametral Tests

	NAME	DATE		franklin geotechnical engineering	
Drawn By	Doug McKechnie	29 April '85			
Checked By				PROJECT: G335.1	FIGURE: 17
Revisions					

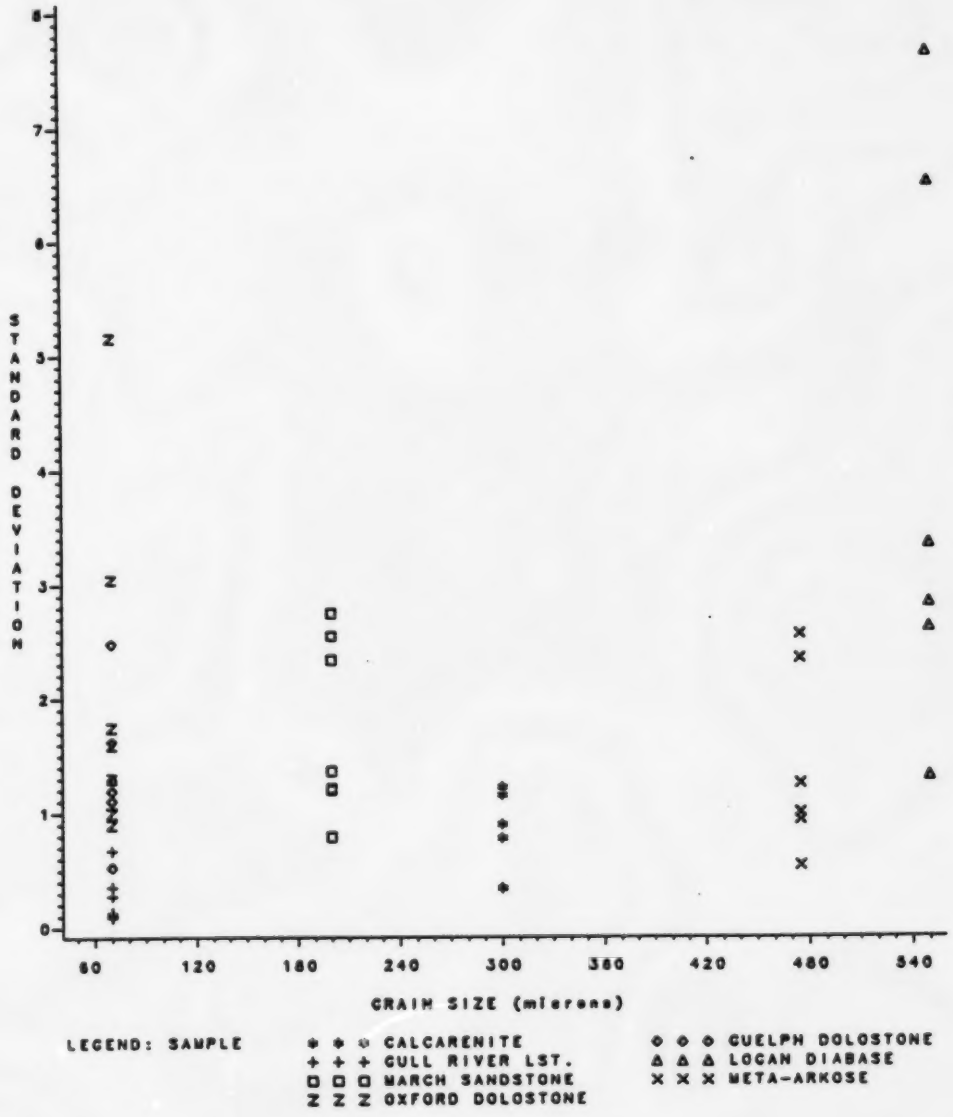


Fig. 18: Standard Deviation
of Point Load Strength vs. Grain Size
for all Diametral Tests

	NAME	DATE		franklin geotechnical engineering	
Drawn By	Doug McLeod	24 April 85			
Checked By				PROJECT: G335.1	FIGURE: 18
Revisions					

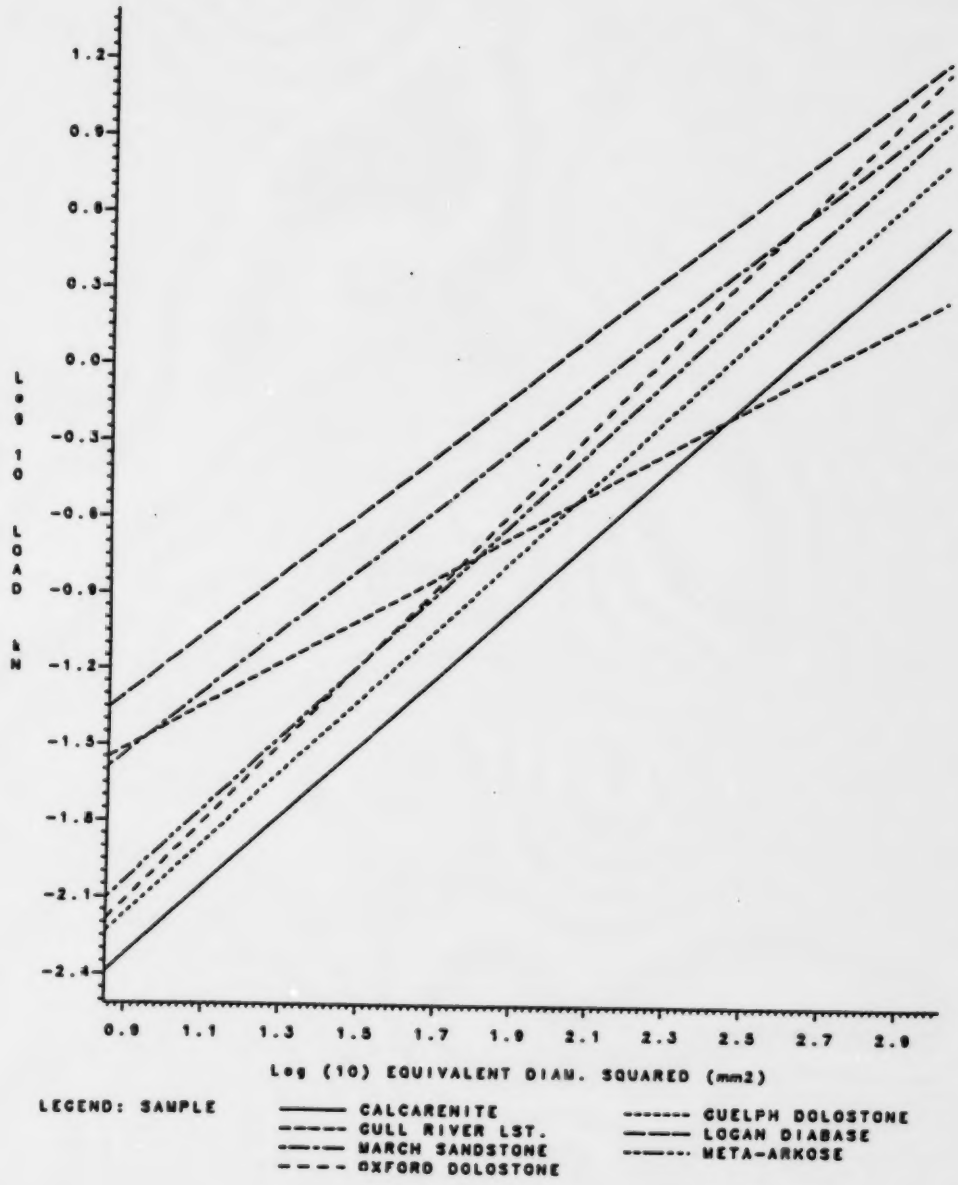


Fig. 19: Log load vs. Log Equivalent Diameter Squared for all Irregular Lump Tests

	NAME	DATE		franklin geotechnical engineering	
Drawn By	Doug McLachlin	2nd April '85			
Checked By					
Revisions				PROJECT: G335.1	FIGURE: 19

Sample	D/W for 105 specimens	Range over 15 tests
Oxford Dolostone	0.50	0.38 - 0.56
Guelph Dolostone	0.57	0.46 - 0.68
March Sandstone	0.54	0.43 - 0.62
Meta-Arkose	0.57	0.49 - 0.61
Logan Diabase	0.50	0.38 - 0.58
Gull River Limestone	0.48	0.41 - 0.53
Coquinoid Calcarenite	0.61	0.53 - 0.73

Fig. 20: Average Ratio of D/W for each Rock Type

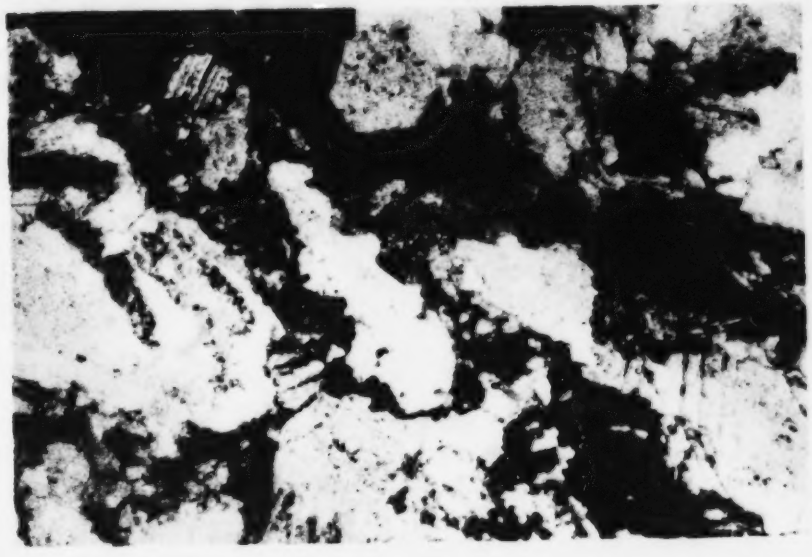
Sample	UCS	Is50	Ratio
Gull River limestone (D)	176 MPa	2.4 MPa	73.3
Gull River limestone (A)	176 MPa	3.1 MPa	56.8
Guelph dolostone	145 MPa	6.3 MPa	23.0

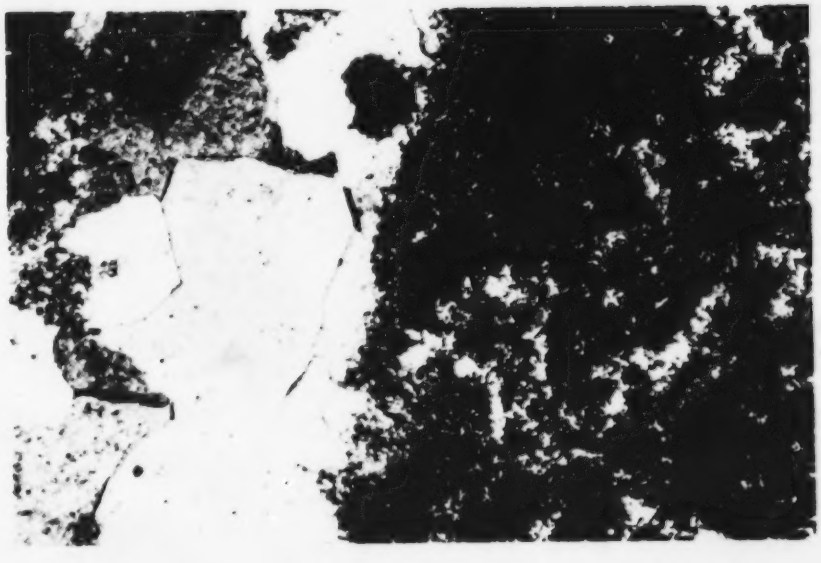
Fig. 21: Uniaxial Compressive and Point Load Strengths of the Two Rock Types Tested

	NAME	DATE	franklin geotechnical engineering	
Drawn By	Doug McLeod	24 April '85		
Checked By			PROJECT: G335.1	FIGURE: 20 & 21
Revisions				

Appendix 1

Thin Section Photomicrographs





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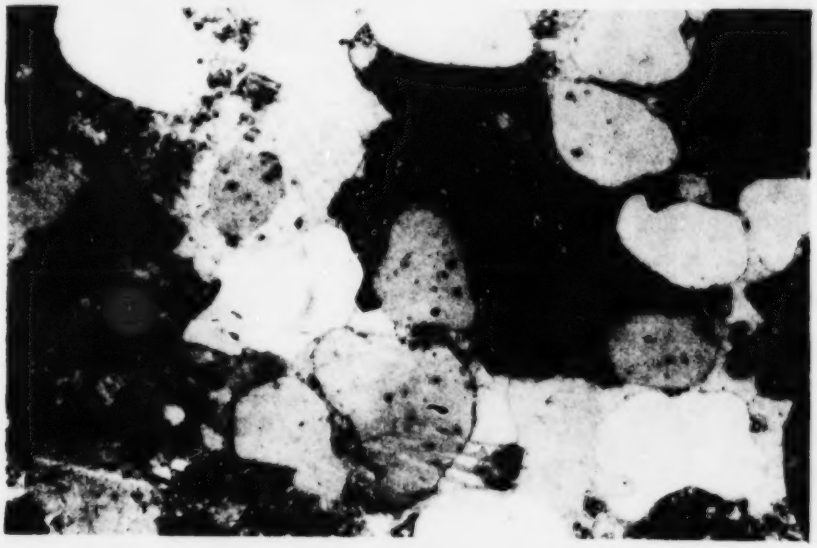
Revisions		

franklin geotechnical engineering

PROJECT:	FIGURE:



	NAME	DATE
Drawn By		
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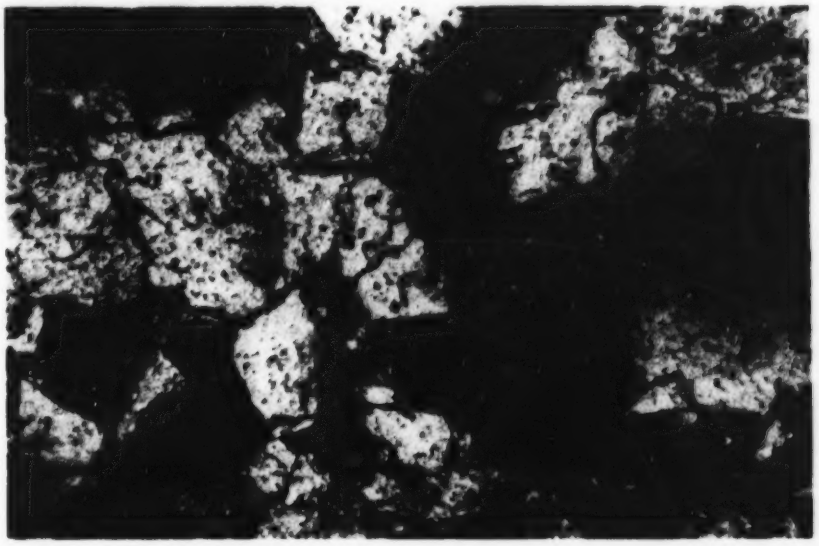
Revisions		

franklin geotechnical engineering

PROJECT:	FIGURE:



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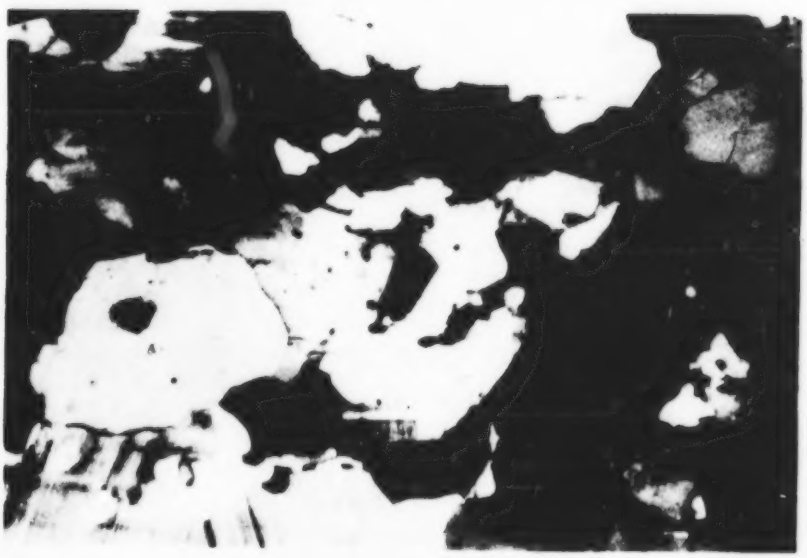
Drawn By		
Checked By		
Revisions		

franklin geotechnical engineering

PROJECT:	FIGURE:



	NAME	DATE		franklin geotechnical engineering	
Drawn By					
Checked By					
Revisions				PROJECT:	FIGURE:

Appendix 2

Development of Point Load Tester Electronics

RESEARCH AND DEVELOPMENT PROJECT 23212 – POINT LOAD TESTING

A. Introduction

Two prototypes of the point load electronic devices have have been developed. They are very similar. The first one is designed for two strain gauge inputs (pressure and displacement) from the mechanical point load tester. Since the mechanical device needed to be modified, the displacement strain gauge transducer was replaced by a linear voltage displacement transducer (LVDT).

At this stage, the electronic input and output board can communicate with the mechanical pump and microprocessor. The software is developed enough to capture the load (P) and displacement (D) at the break point during aggregate tests. No point load strength index Is(50) calculation is provided $Is(50) = (P/D^2)\ (\sqrt[N]{D/50})$. The electronic package is operated by an A.C. source.

In order to meet the target for portability and to store a series of the point load strength index data, the final prototype will be as small and light-weight as possible and the software also will be expanded.

A simplified block diagram of the second prototype is shown in Figure 1 (a) and (b). Its software flowchart is detailed in Figure 2.

B. System Description for the Second Prototype (presently used)

The hardness of a material is determined by two factors. The pressure required to break it and the compressibility of the material. The point load tester tests for both these factors simultaneously. There are four major components to the tester. These are:

1/ the pressure tester
2/ the point platens and displacement transducer
3/ MEK 6800D2 microprocessor evaluation kit
4/ input and output interface package

1/ the pressure tester – The pressure transducer from the mechanical device indicates how much pressure is being applied to the material under test. Since the input signal is in the micro-volt range, it needed to be amplified and the noise filtered, after that it will be converted into 16-bit digital form through ADC1140 convertor. Maximum applied load is 5000 lb-f.

2/ the point load platens – The point load tester has two platens that come to a point. One is fixed while the other is movable inside a piston arrangement. The movement of an LVDT mounted inside the piston indicates how much the piston has moved, when the material under the test cracks. Also the incoming signal needed to be sampled into 16-bit digital form. Max. diameter of the tested material is 1 5/8 inches.

3/ MEK 6800D2 microprocessor evaluation kit – The microprocessor kit is used in our laboratory for general purpose. Its size is bigger than what the design needed. This kit is only used for experimental demonstration. It has an audio cassette input. We assign its one peripheral interface adapter (PIA) as the input and output port. PIA consists of two parts called PIA-A and PIA-B. Each part has 8 data lines (DO to D7) and two control lines (CAI. CA2 /CB1. CB2). Figure 1 (b) shows us the general idea how the control lines do their functions.

4/ Input and output interface package (refer to Figure 1 (a) and 1 (b)) – The reset button is MEK6800D2 kit normally sets the four control lines to low level before the materials are tested. Once the start switch is turned on, CB2 control line sends a command pulse to sample the pressure and displacement signals. At the same time CA2, CB2 control lines select the multiplexer and switch CD4016. so that the pressure sampled signal will be able to input 16 bits of data to the ports PIA-A (DO-D7) and PIA-B (DO-D7). These ports had already been programmed as input.

Normally the ADC1140 convertor takes 35 μ sec. to finish sampling, after that its status line automatically sends back a pulse to CB1 indicating the sampling process is finished.

After storing the 16 bits of pressure data into the assigned memory locations. the microprocessor scans the feedback status pulse from the displacement convertor. This data is captured and called initial values for later use.

As the material is being loaded, the four control lines perform the same procedure as mentioned before. but every time. the pressure data is updated to determine its maximum value in an attempt to capture the peak value when the materials cracked. Since the cracked material is still held by the piston after the test is completed. particularly when testing soft materials. we cannot assume the applied load is always reduced to zero. We use a 10 lb-f limit instead of zero to automatically stop the test (refer to Figure 2 flowchart).

After the pressure and displacement data are converted to engineering units (1 volt equivalent to 1000 lb-f or 1 inch), PIA-B is assigned as an 8-bit output port. CA2, CB2 control the switch CD4016 so that each time it dumps a pair of digits from the memory locations to LED output drivers under the selected control lines. Pressure and displacement outputs each have six digits with decimal point. When the test is finished, red and green signal lights automatically turn off.

C. The Proposed Final Prototype

The front end of the system should be the same as mentioned before (refer to Figure 3). This time the design may use one A/D convertor instead of two to handle pressure and displacement incoming signals. The reasons for this choice is that it will reduce the size of package and the cost, but on the other hand, the two measurements would lag in time about 100 μ sec.

The microcomputer consists of three parts – CPU, memory and the LCD display logic. Motorola 146805E2P microprocessor will be selected. This is a CMOS type consuming very little power. There will be more functions in the software package. As well as capturing P and D. it will calculate Is(50) point load strength and store up to 50 results in memory locations. All calculations of load, displacement and strength should be displayed in S.I. units. A manual methodof determining the 'end of test' condition would be more suitable because of the shape and hardness of materials. The whole package will be operated by 6 V. battery. A simplified block diagram of the final prototype is shown in Figure 3 and 4.

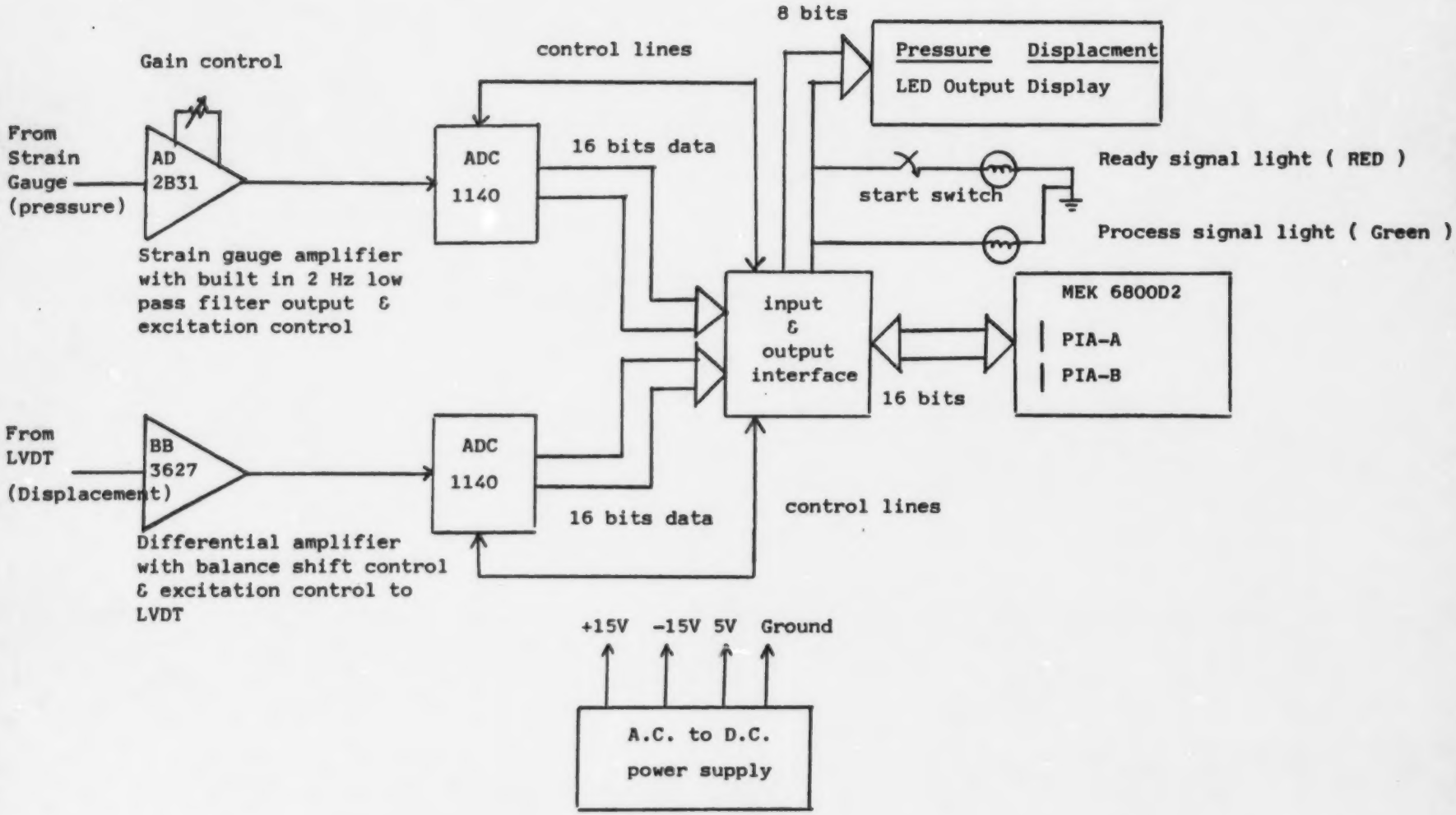
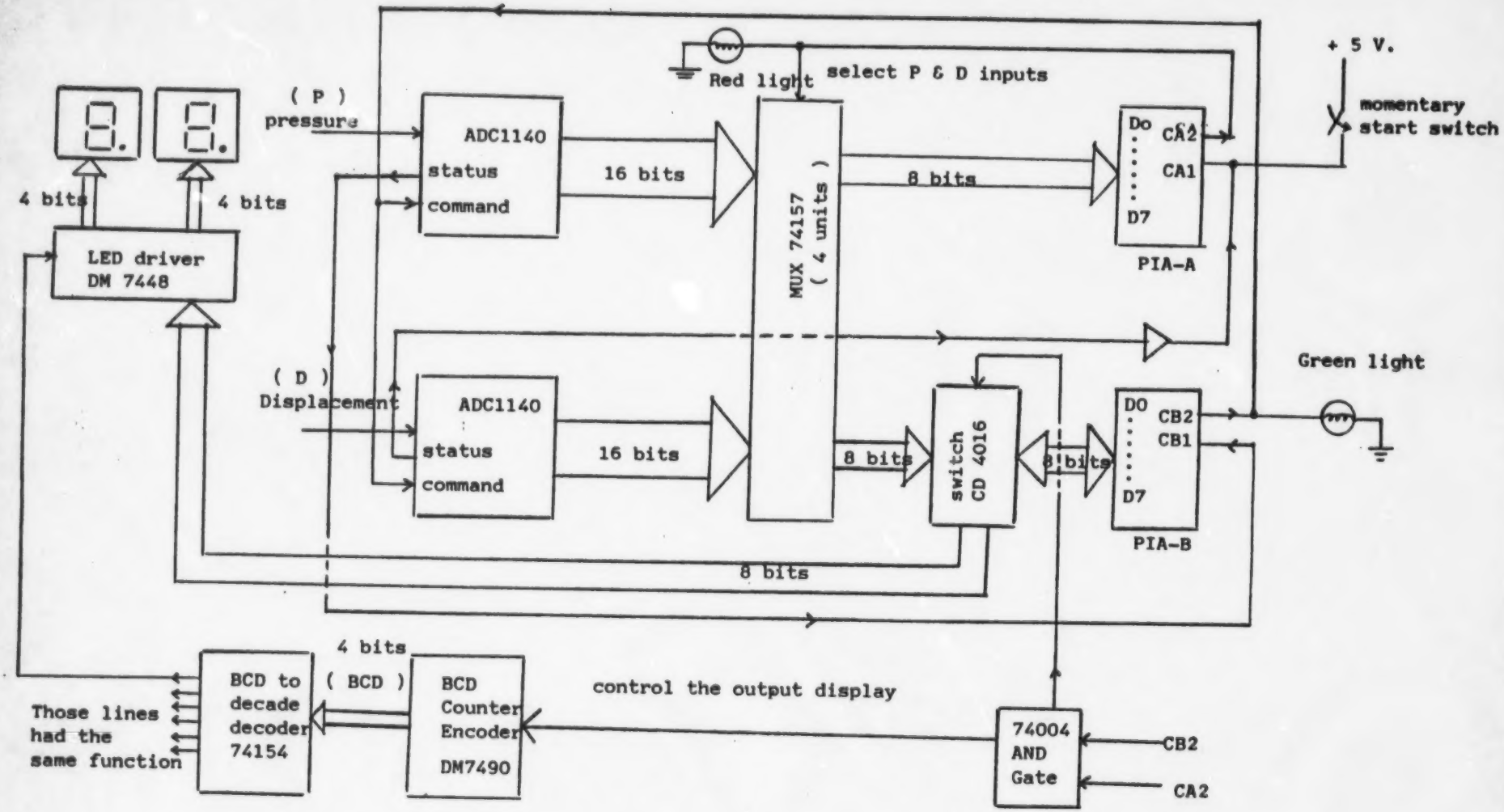

8 bits
control lines
Gain control
Pressure Displacment
LED Output Display
From
Strain
Gauge
(pressure)
AD
2B31
ADC
1140
16 bits data
Ready signal light (RED)
start switch
Process signal light (Green)
Strain gauge amplifier
with built in 2 Hz low
pass filter output &
excitation control
input
&
output
interface
MEK 6800D2
PIA-A
PIA-B
16 bits
From
LVDT
(Displacement)
BB
3627
ADC
1140
16 bits data
control lines
Differential amplifier
with balance shift control
& excitation control to
LVDT
+15V -15V 5V Ground
A.C. to D.C.
power supply

FIGURE 1 (a)



Input & Output interface configuration Figure 1 (b)

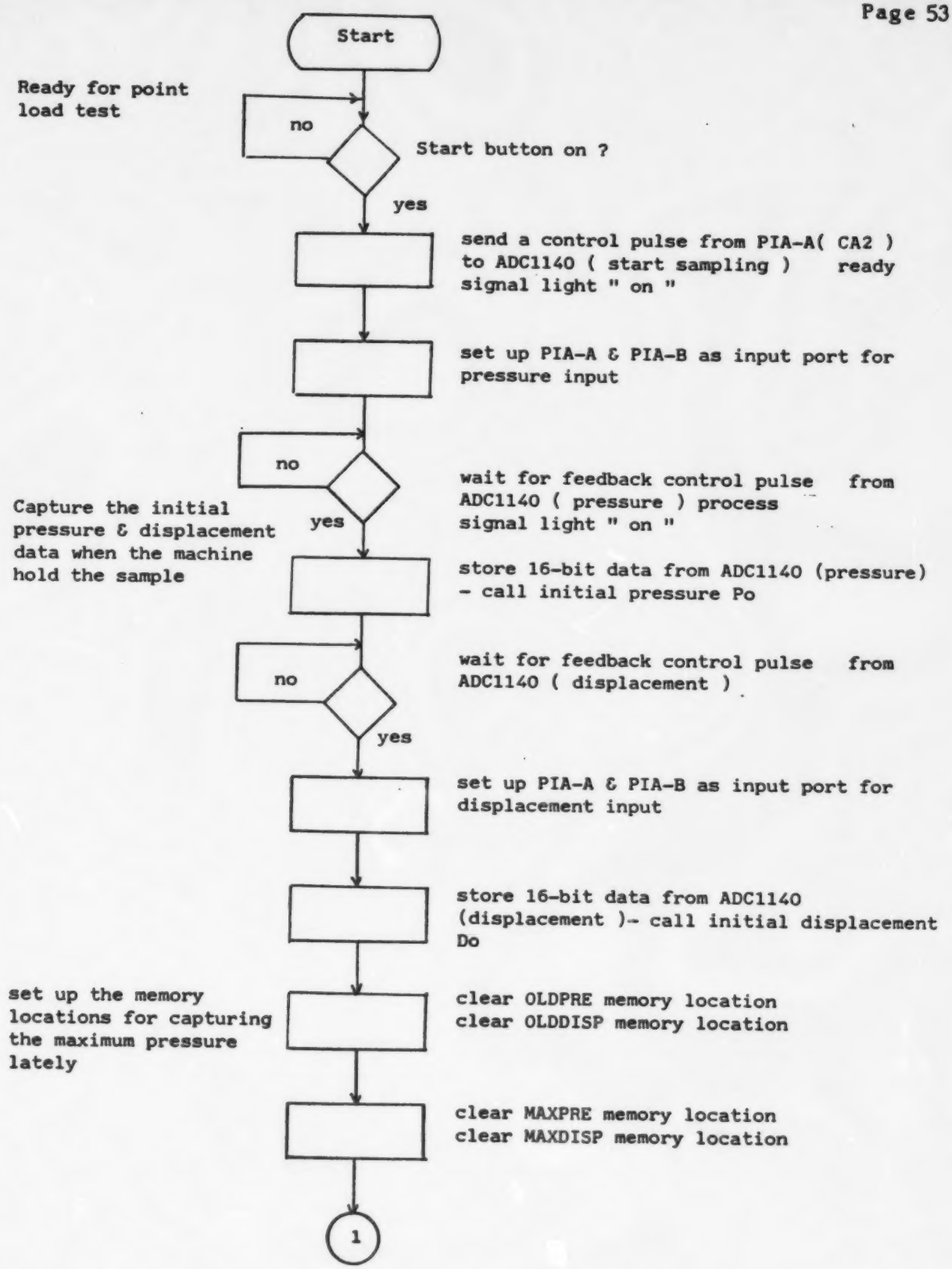
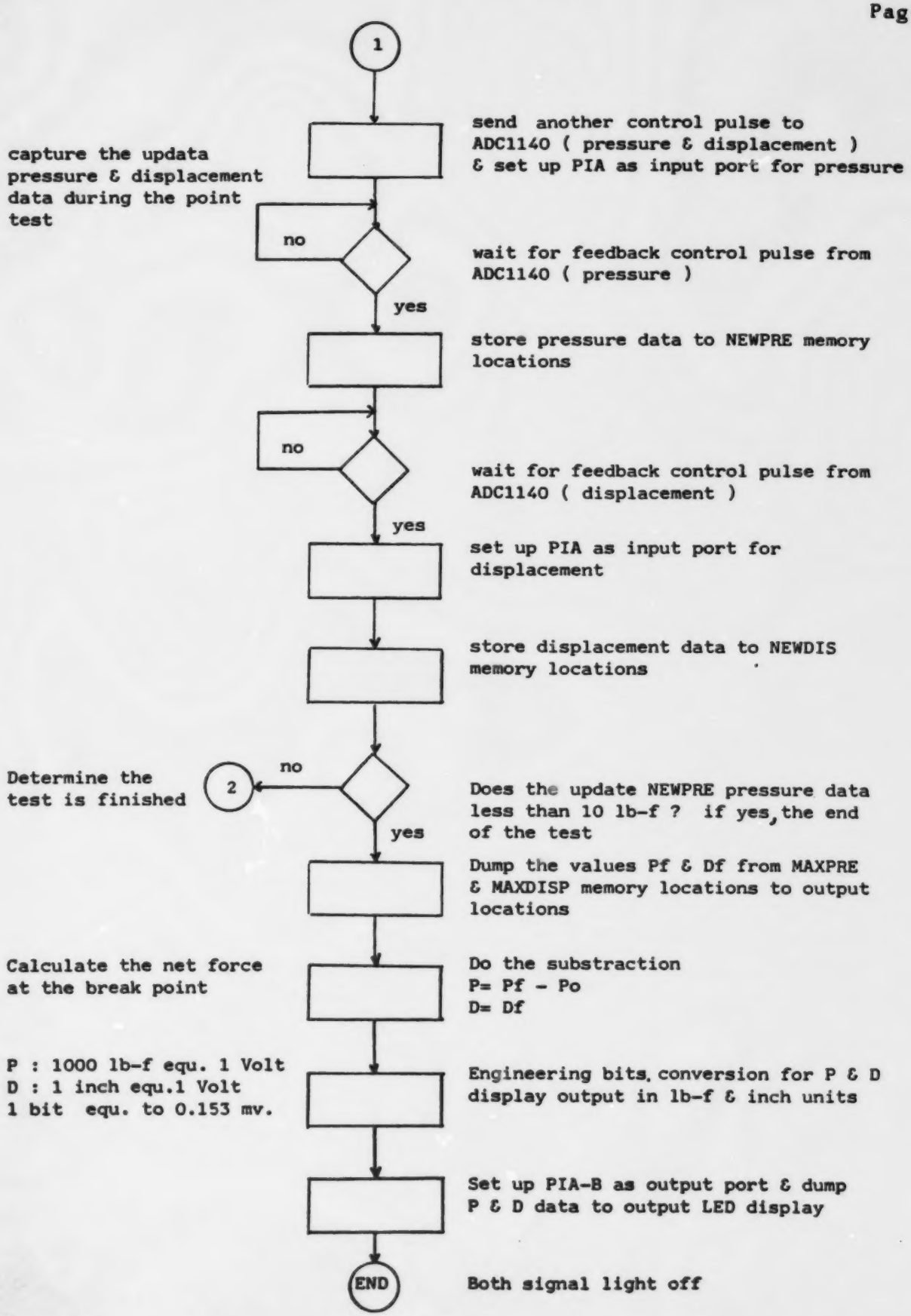
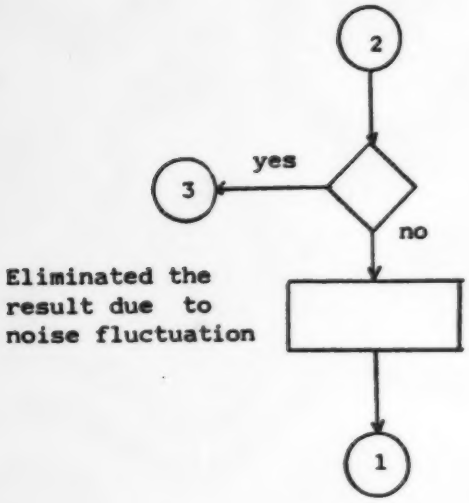

Start
Ready for point load test
no
Start button on ?
yes
send a control pulse from PIA-A(CA2) to ADC1140 (start sampling) ready signal light " on "
set up PIA-A & PIA-B as input port for pressure input
no
wait for feedback control pulse from ADC1140 (pressure) process signal light " on "
Capture the initial pressure & displacement data when the machine hold the sample
yes
store 16-bit data from ADC1140 (pressure) - call initial pressure Po
no
wait for feedback control pulse from ADC1140 (displacement)
yes
set up PIA-A & PIA-B as input port for displacement input
store 16-bit data from ADC1140 (displacement)- call initial displacement Do
set up the memory locations for capturing the maximum pressure lately
clear OLDPRE memory location
clear OLDDISP memory location
clear MAXPRE memory location
clear MAXDISP memory location
1

Figure 2

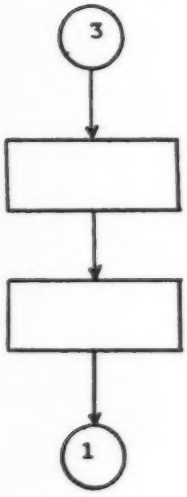

1
send another control pulse to ADC1140 (pressure & displacement) & set up PIA as input port for pressure
capture the updata pressure & displacement data during the point test
no
wait for feedback control pulse from ADC1140 (pressure)
yes
store pressure data to NEWPRE memory locations
no
wait for feedback control pulse from ADC1140 (displacement)
yes
set up PIA as input port for displacement
store displacement data to NEWDIS memory locations
Determine the test is finished
2
no
Does the update NEWPRE pressure data less than 10 lb-f ? if yes, the end of the test
yes
Dump the values Pf & Df from MAXPRE & MAXDISP memory locations to output locations
Calculate the net force at the break point
Do the substraction
P= Pf - Po
D= Df
P : 1000 lb-f equ. 1 Volt
D : 1 inch equ.1 Volt
1 bit equ. to 0.153 mv.
Engineering bits conversion for P & D display output in lb-f & inch units
Set up PIA-B as output port & dump P & D data to output LED display
END
Both signal light off



NEWPRE data- OLDPRE data $\geq$ 10 lb-f

Eliminated the result due to noise fluctuation

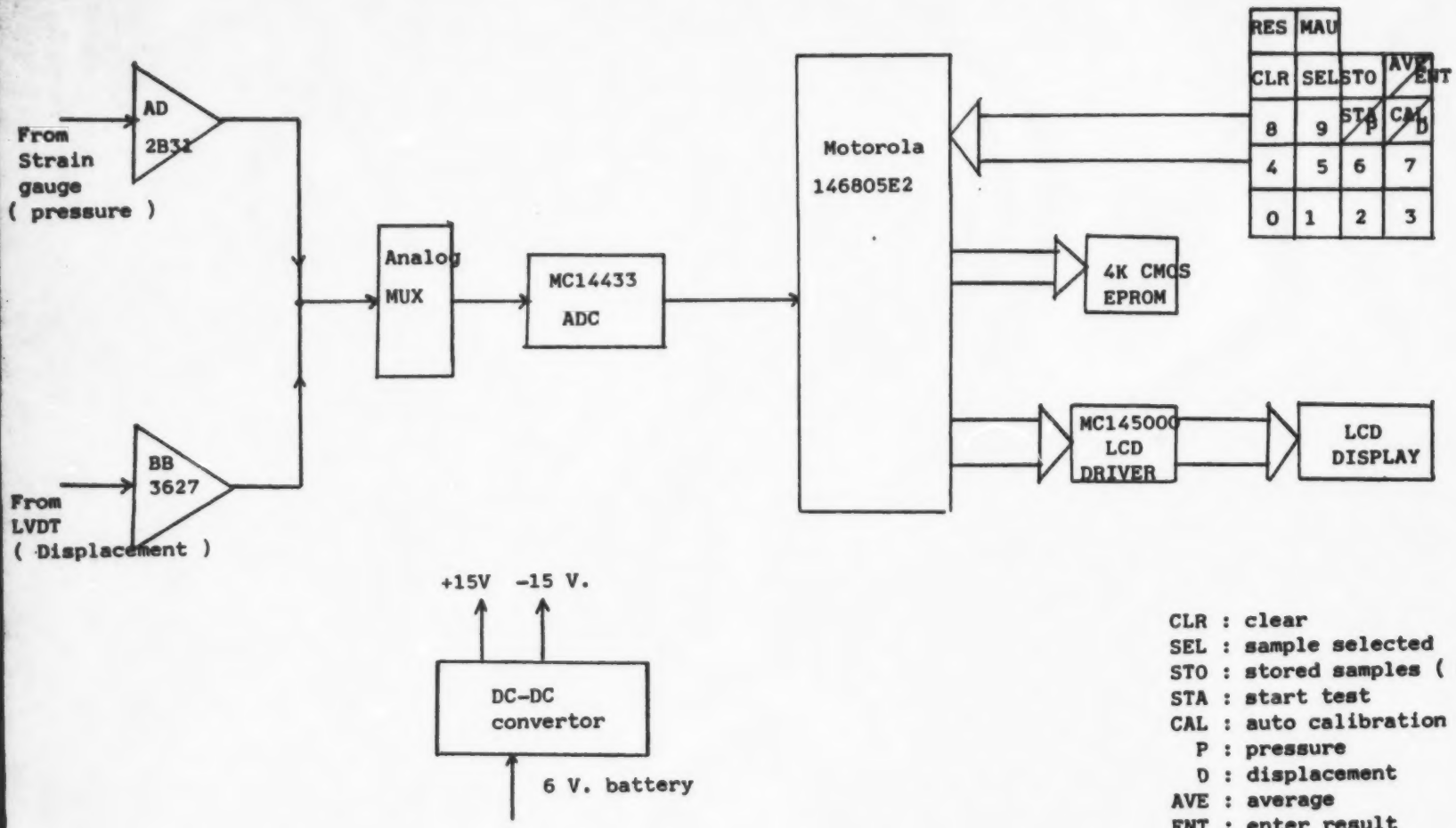
NEWPRE $\longrightarrow$ OLDPRE
NEWDISP $\longrightarrow$ OLDDISP



Keep track the maximum load during the test

NEWPRE $\longrightarrow$ OLDPRE
NEWDISP $\longrightarrow$ OLDDISP

NEWPRE $\longrightarrow$ MAXPRE
NEWDISP $\longrightarrow$ MAXDISP



CLR : clear
SEL : sample selected
STO : stored samples (up to 50 results
STA : start test
CAL : auto calibration
P : pressure
D : displacement
AVE : average
ENT : enter result
RES : reset
MAU : manual stop the test

Figure 3

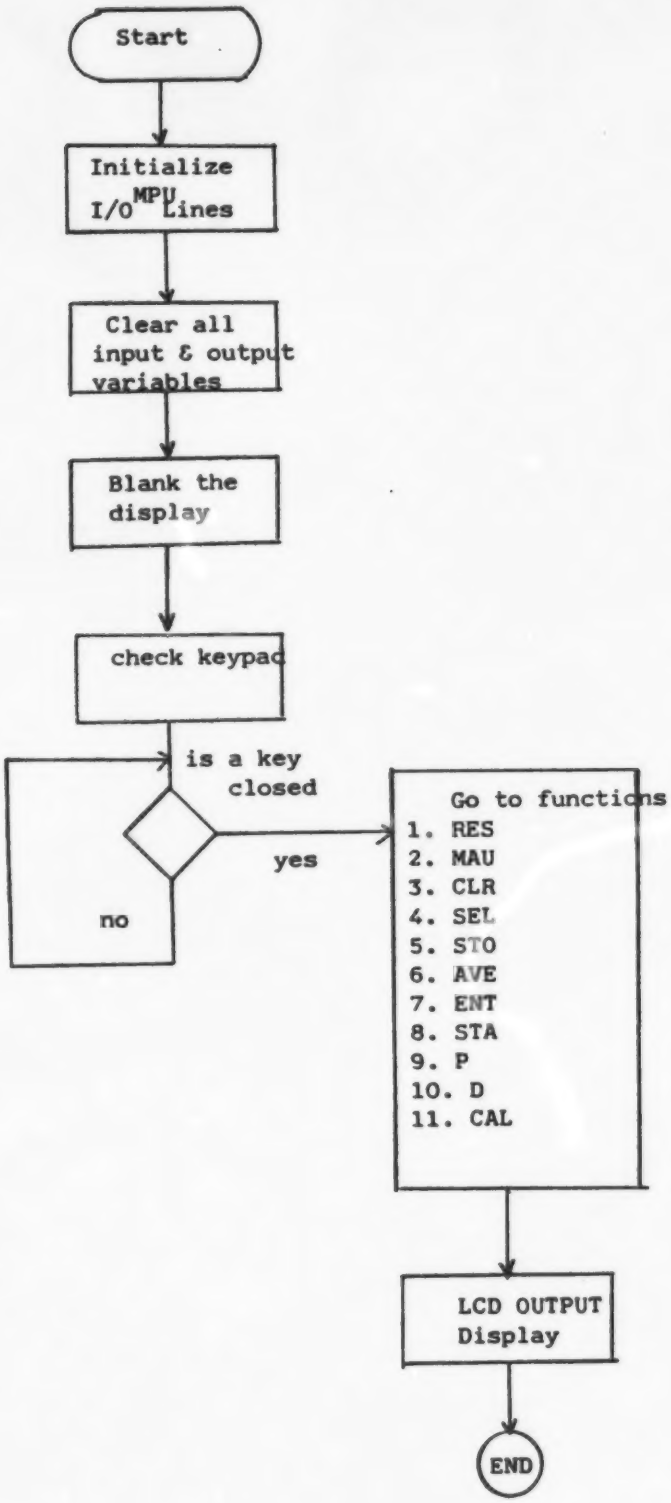

Start
Initialize MPU I/O Lines
Clear all input & output variables
Blank the display
check keypad
is a key closed
yes
no
Go to functions
1. RES
2. MAU
3. CLR
4. SEL
5. STO
6. AVE
7. ENT
8. STA
9. P
10. D
11. CAL
LCD OUTPUT Display
END

Figure 4

Appendix 3

ISRM Suggested Method of Testing

Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. Vol. 00, pp. 000–000. 1984
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INTERNATIONAL SOCIETY FOR ROCK MECHANICS

COMMISSION ON TESTING METHODS

Working Group on Revision of the Point Load Test Method

SUGGESTED METHOD FOR DETERMINING POINT LOAD STRENGTH

(to replace original document published in 1972)

JUNE, 1984

INTRODUCTION

The ISRM Commission on Testing Methods, formerly the Commission on Standardization of Laboratory and Field Tests, was established in 1967. Its main task is the drafting of "Suggested Methods' for rock testing. Its aim is to achieve some measure of standardization without inhibiting the development and improvement of techniques.

The Point Load Strength Test was one of the first to be published (in 1972) by this Commission, and is one of the first to be revised. The outcome of earlier "indirect tensile tests" such as those by Protodyakanov in Russia and by Hobbs in England, it was first described in its present form as a rock strength index test by Franklin *et al.* [1] and by Broch and Franklin [2]. References to the early history of the test may be found in the latter publication.

Subsequent research as detailed in the accompanying bibliography has added greatly to our understanding of the test and has led, for example, to much simpler, more direct and reliable size and shape correction procedures than those first published. The authors of this research were invited to form a working group for revision of the Suggested Method. The revised version is a concensus of their comments and opinions.

The test is primarily intended as an index for rock classification and characterization. As an index test it needs to be simple, and we have tried to retain its essential simplicity in this revised version.

Acknowledgements—The following made major contributions to the editing and revision of this Suggested Method: J. A. Franklin (Working Group Co-ordinator, *Canada*); P. Pells (*Australia*); D. McLachlin (*Canada*); N. Brook and P. J. Robins (*England*); M. Greminger and H. Kutter (*F.R. Germany*); E. Broch (*Norway*); W. L. van Heerden and U. W. Vogler (*South Africa*) and G. Wijk (*Sweden*).

Suggested Method for Determining Point Load Strength

SCOPE

1.(a) The Point Load Strength test is intended an an index test for the strength classification of rock materials. It may also be used to predict other strength parameters with which it is correlated, for example uniaxial tensile and compressive strength.[1]

(b) The test measures the Point Load Strength Index ($I_{s(50)}$) of rock specimens, and their Strength Anisotropy Index ($I_{a(50)}$) which is the ratio of Point Load Strengths in strongest and weakest directions.

(c) Rock specimens in the form of either core (the *diametral* and *axial* tests), cut blocks (the *block* test), or irregular lumps (the *irregular lump* test) are broken by application of concentrated load through a pair of spherically truncated, conical platens.[2] Little or no specimen preparation is needed.

(d) The test can be performed with portable equipment or using a laboratory testing machine, and so may be conducted either in the field or the laboratory.

APPARATUS

2. The testing machine (Fig. 1) consists of a loading system (for the portable version typically comprising a loading frame, pump, ram and platens), a system for measuring the load P required to break the specimen, and a system for measuring the distance D between the two platen contact points (but see 5(e) below).

Loading system

3.(a) The loading system should have a platen-to-platen clearance that allows testing of rock specimens in the required size range. Typically this range is 15–100 mm so that an adjustable clearance is needed to accommodate both small and large specimens.

(b) The loading capacity should be sufficient to break the largest and strongest specimens to be tested.[3]

(c) The test machine should be designed and constructed so that it does not permanently distort during repeated applications of the maximum test load, and so that the platens remain co-axial within $\pm$ 0.2 mm throughout the testing. No spherical seat or other non-rigid component is permitted in the loading system. Loading system rigidity is essential to avoid problems of slippage when specimens of irregular geometry are tested.

(d) Spherically-truncated, conical platens of the standard geometry shown in Fig. 2 are to be used. The 60° cone and 5 mm radius spherical platen tip should meet tangentially.[4] The platens should be of hard material such as tungsten carbide or hardened steel so that they remain undamaged during testing.

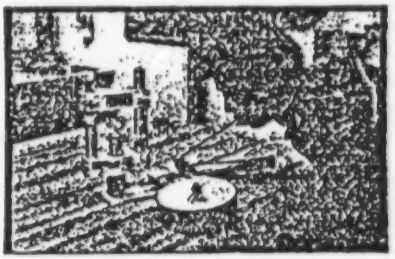

Fig. 1. Photograph of portable point load test machine.

Load measuring system

4.(a) The load mesuring system, for example a load cell or a hydraulic pressure gauge or transducer connected to the ram, should permit determination of the failure load P required to break the specimen and should conform to the requirements (b) through (d) below.

(b) Measurements of P should be to an accuracy of $\pm$ 5%P or better, irrespective of the size and strength of specimen that is tested.[3,5]

(c) The system is to be resistant to hydraulic shock and vibration so that the accuracy of readings is not adversely affected by repeated testing.

(d) Failure is often sudden and a maximum load indicating device is essential so that the failure load is retained and can be recorded after each test.

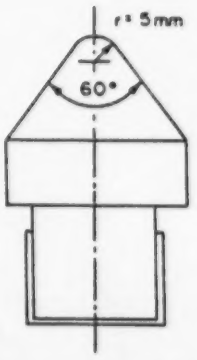

Fig. 2. Platen shape and tip radius.

* Superscript numbers refer to Notes at the end of the text.

Distance measuring system

5.(a) The distance measuring system, for example a direct reading scale or displacement transducer, is to permit measurement of the distance D between specimen-platen contact points and should conform with requirements (b) through (d) below.[6]

(b) Measurements of D should be to an accuracy of $\pm 2\%D$ or better irrespective of the size of specimen tested.

(c) The system is to be resistant to hydraulic shock and vibration so that the accuracy of readings is not adversely affected by repeated testing.

(d) The measuring system should allow a check of the "zero displacement" value when the two platens are in contact, and should preferably include a zero adjustment.

(e) An instrument such as calipers or a steel rule is required, to measure the width W of specimens for all but the diametral test.

PROCEDURE

Specimen selection and preparation

6.(a) A test sample is defined as a set of rock specimens of similar strength for which a single Point Load Strength value is to be determined.

(b) The test sample of rock core or fragments is to contain sufficient specimens conforming with the size and shape requirements for diametral, axial, block or irregular lump testing as specified below.[7]

(c) For routine testing and classification, specimens should be tested either fully water-saturated or at their natural water content.[8]

Calibration

7. The test equipment should be periodically calibrated using an independently certified load cell and set of displacement blocks, checking the P and D readings over the full range of loads and displacements pertinent to testing.

The diametral test[2]

8.(a) Core specimens with length/diameter ratio greater than 1.0 are suitable for diametral testing.

(b) There should preferably be at least 10 tests per sample, more if the sample is heterogeneous or anisotropic.[7]

(c) The specimen is inserted in the test machine and the platens closed to make contact along a core diameter, ensuring that the distance L between the contact points and the nearest free end is at least 0.5 times the core diameter (Fig. 3a).

(d) The distance D is recorded $\pm 2\%$.[6]

(e) The load is steadily increased such that failure occurs within 10–60 sec, and the failure load P is recorded. The test should be rejected as not valid if the

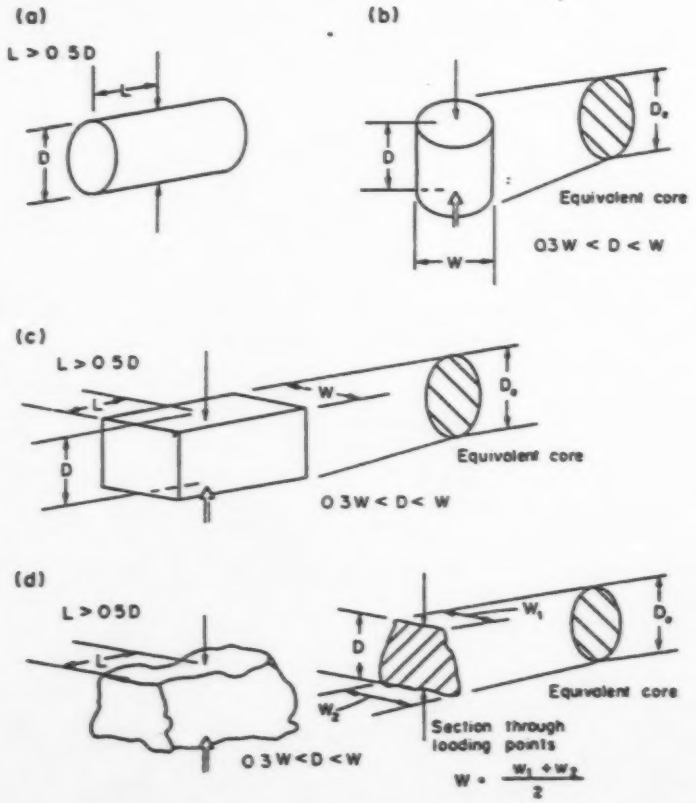

Fig. 3. Specimen shape requirements for (a) the diametral test, (b) the axial test, (c) the block test, and (d) the irregular lump test.

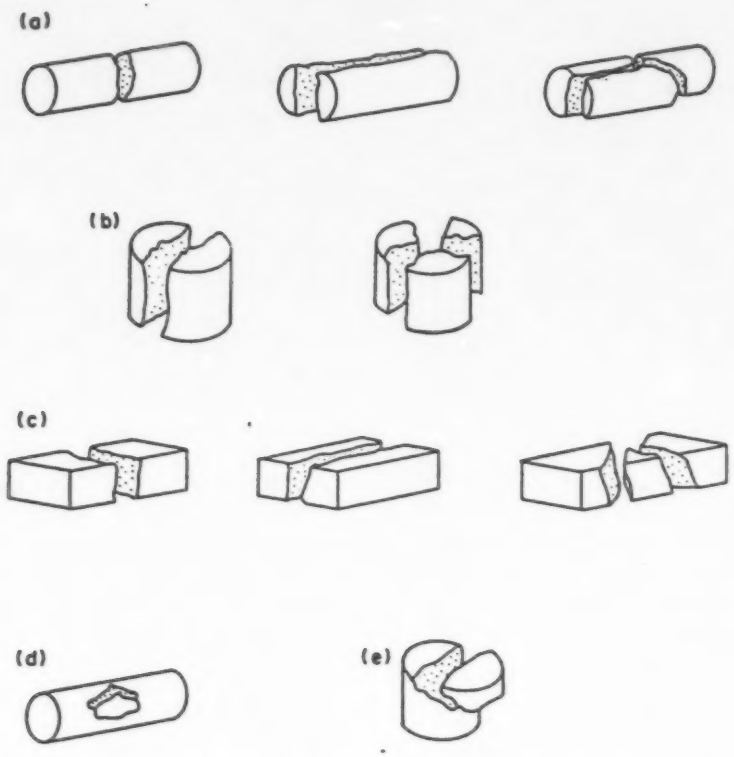

Fig. 4. Typical modes of failure for valid and invalid tests. (a) Valid diametral tests; (b) valid axial tests; (c) valid block tests; (d) invalid core test; (e) invalid axial test.

fracture surface passes through only one loading point (Fig. 4d).

(f) The procedure (c) through (e) above is repeated for the remaining specimens in the sample.

The axial test[2]

9.(a) Core specimens with length/diameter ratio of 0.3–1.0 are suitable for axial testing (Fig. 3b). Long pieces of core can be tested diametrally to produce suitable lengths for subsequent axial testing (provided that they are not weakend by this initial testing); alternatively, suitable specimens can be obtained by saw-cutting or chisel-splitting.

(b) There should preferably be at least 10 tests per sample, more if the sample is heterogeneous or anisotropic.

(c) The specimen is inserted in the test machine and the platens closed to make contact along a line perpendicular to the core end faces (in the case of isotropic rock, the core axis, but see paragraph 11 and Fig. 5).

(d) The distance D between platen contact points is recorded $\pm$ 2%.[6] The specimen width W perpendicular to the loading direction is recorded $\pm$ 5%.[9]

(e) The load is steadily increased such that failure occurs within 10–60 sec, and the failure load P is recorded. The test should be rejected as invalid if the fracture surface passes through only one loading point (Fig. 4e).

(f) The procedures (c) through (e) above are repeated for the remaining tests in the sample.

The block and irregular lump tests

10.(a) Rock blocks or lumps of size 50 ± 35 mm and of the shape shown in Fig. 3(c) and (d) are suitable for the block and the irregular lump tests. The ratio D/W should be between 0.3 and 1.0, preferably close to 1.0.

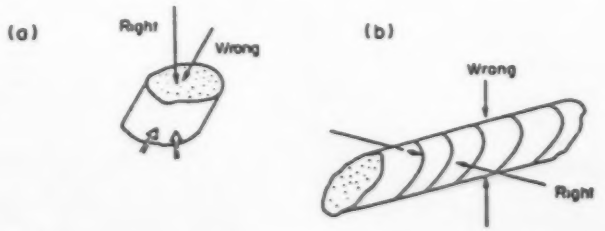

Fig. 5. Loading directions for tests on anisotropic rock.

The distance L (Fig. 3c and d) should be at least $0.5W$. Specimens of this size and shape may be selected if available or may be prepared by trimming larger pieces by saw-or chisel-cutting.

(b) There should preferably be at least 10 tests per sample, more if the rock is heterogeneous or anisotropic.[7]

(c) The specimen is inserted in the testing machine and the platens closed to make contact with the smallest dimension of the lump or block, away from edges and corners (Fig. 3c and d).

(d) The distance D between platen contact points is recorded $\pm 2\%$. The smallest specimen width W perpendicular to the loading direction is recorded $\pm 5\%$. If the sides are not parallel, then W is calculated as $(W_1 + W_2)/2$ as shown in Fig. 3d.[6] This smallest width W is used irrespective of the actual mode of failure (Figs 3 and 4)

(e) The load is steadily increased such that failure occurs within 10–60 sec, and the failure load P is recorded. The test should be rejected as not valid if the fracture surface passes through only one loading point (see examples for other shapes in Fig. 4d or e).

(f) The procedure (c) through (e) above is repeated for the remaining tests in the sample.

Anisotropic Rock

11. (a) When a rock sample is shaly, bedded, schistose or otherwise observably anisotropic it should be tested in both the weakest and strongest directions which are in general parallel and normal to the planes of anisotropy.

(b) If the sample consists of core drilled through the weakness planes, a set of diametral tests may be completed first, spaced at intervals which will yield pieces which can then be tested axially.

(c) Best results are obtained when the core axis is perpendicular to the planes of weakness, so that when possible the core should be drilled in this direction. The angle between the core axis and the weakness planes should preferably not exceed 30°.

(d) For measurement of the I_s value in the weakest direction, care should be taken to ensure that load is applied along a single weakness plane. Similarly when testing for the I_s value in the strongest direction, care should be taken to ensure that the load is applied perpendicularly to the weakness planes (Fig. 5).

(e) If the sample consists of blocks or irregular lumps, it should be tested as two sub-samples, with load applied firstly perpendicular to, then along the observable planes of weakness.[10] Again, the required minimum strength value is obtained when the platens make contact along a single plane of weakness.

CALCULATIONS

Uncorrected point load strength

12. The Uncorrected Point Load Strength I_s is calculated as P/D_e^2 where D_e, the "equivalent core diameter", is given by:

$D_e^2 = D^2$ for diametral tests;

$= 4A/\pi$ for axial, block and lump tests;

and

$A = WD$ = minimum cross sectional area of a plane through the platen contact points.[6]

Size correction

13.(a) I_s varies as a function of D in the diametral test, and as a function of D_e in axial, block and irregular lump tests, so that a size correction must be applied to obtain a unique Point Load Strength value for the rock sample, and one that can be used for purposes of rock strength classification.

(b) The size-corrected Point Load Strength Index $I_{s(50)}$ of a rock specimen or sample is defined as the value of I_s that would have been measured by a diametral test with $D = 50$ mm.

(c) The most reliable method of obtaining $I_{s(50)}$, preferred when a precise rock classification is essential, is to conduct diametral tests at or close to $D = 50$ mm. Size correction is then either unnecessary ($D = 50$ mm) or introduces a minimum of error. The latter is the case, for example, for diametral tests on NX core, $D = 54$ mm. This procedure is not mandatory. Most point load strength testing is in fact done using other sizes or shapes of specimen. In such cases, the size correction (d) or (e) below must be applied.

(d) The most reliable method of size correction is to test the sample over a range of D or D_e values and to plot graphically the relation between P and D_e^2. If a log–log plot is used the relation is generally a straight line (Fig. 6). Points that deviate substantially from the straight line may be disregarded (although they should not be deleted). The value of P_{50} corresponding to $D_e^2 = 2500$ mm^2 ($D_e = 50$ mm) can then be obtained by interpolation, if

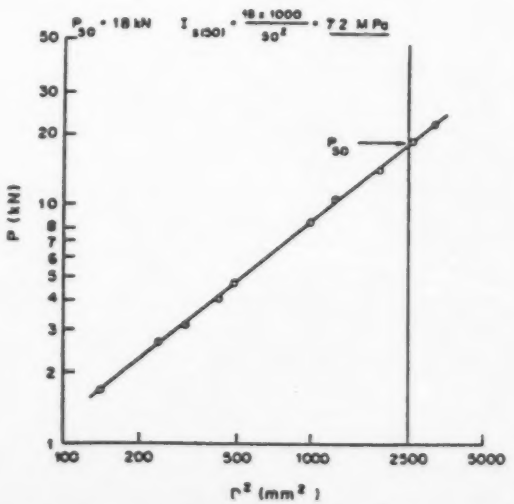

Fig. 6. Procedure for graphical determination of $I_{s(50)}$ from a set of results at D_e values other than 50 mm.

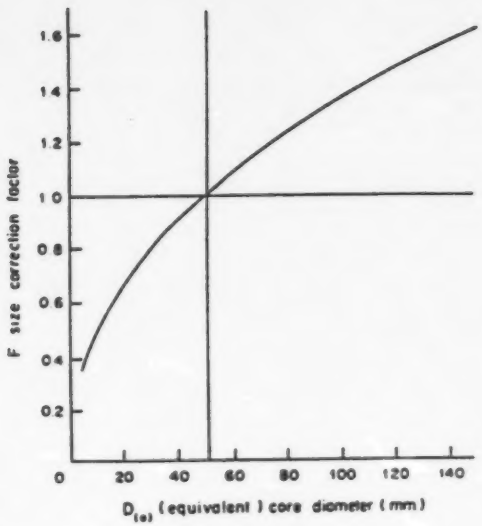

Fig. 7. Size correction factor chart.

necessary by extrapolation, and the size-corrected Point Load Strength Index calculated as $P_{50}/50^2$.

(e) When neither (c) nor (d) is practical, for example when testing single sized core at a diameter other than 50 mm or if only a few small pieces are available, size correction may be accomplished by using the formula:

$$I_{s(50)} = F \times I_s$$

The "Size Correction Factor F" can be obtained from the chart in Fig. 7,[11] or from the expression:

$$F = (D_e/50)^{0.45}$$

For tests near the standard 50 mm size, very little error is introduced by using the approximate expression:

$$F = \sqrt{(D_e/50)}$$

(f) The size correction procedures specified in this paragraph have been found to be applicable irrespective of the degree of anisotropy I_a and the direction of loading with respect to planes of weakness, a result that greatly enhances the usefulness of this test.

Mean value calculation

14.(a) Mean values of $I_{s(50)}$ as defined in (b) below are to be used when classifying samples with regard to their Point Load Strength and Point Load Strength Anisotropy Indices.

(b) The mean value of $I_{s(50)}$ is to be calculated by deleting the two highest and lowest values from the 10 or more valid tests, and calculating the mean of the remaining values. If significantly fewer specimens are tested, only the highest and lowest values are to be deleted and the mean calculated from those remaining.[12]

Point load strength anisotropy index

15. The Strength Anistropy Index $I_{a(50)}$ is defined as the ratio of mean $I_{s(50)}$ values measured perpendicular and parallel to planes of weakness, i.e. the ratio of greatest to least Point Load Strength Indices. $I_{a(50)}$ assumes values close to 1.0 for quasi-isotropic rocks and higher values when the rock is anisotropic.

REPORTING OF RESULTS

16. Results for diametral tests, axial tests, block tests and irregular lump tests, and for tests perpendicular and parallel to planes of weakness should be tabulated separately (see typical results form, Fig. 8). The report should contain calibration data for the test machine and at least the following information for each sample tested:

(a) The sample number, source location and rock type, and the nature and *in situ* orientation of any planes of anistropy or weakness.

(b) Information on the water content of the rock at the time of testing.

(c) Information on which specimens were loaded parallel (//), perpendicular (⊥), or at unknown or random directions with respect to planes of weakness.

(d) A tabulation of the values of P, D, (W, D_e^2 and D_e if required), I_s, (F if required) and $I_{s(50)}$ for each specimen in the sample.

(e) For all isotropic samples, a summary tabulation of mean $I_{s(50)}$ values.

(f) For all anisotropic samples, a summary tabulation of mean $I_{s(50)}$ values for sub-samples tested perpendicular and parallel to the planes of weakness, and of the corresponding $I_{s(50)}$ values.

NOTES

1. When first introduced, the point load strength test was used mainly to predict uniaxial compressive strength which was then the established test for general-purpose rock strength classification. Point load strength now often replaces uniaxial compressive strength in this role since when properly conducted it is as reliable and much quicker to measure. $I_{s(50)}$ should be used directly for rock classification, since correlations with uniaxial compressive strength are only approximate. On average, uniaxial compressive strength is 20–25 times point load strength, as shown in Fig. 9. However, in test on many different rock types the ratio can vary between 15 and 50 especially for anisotropic rocks, so that errors of up to 100% are possible in using an arbitrary ratio value to predict compressive strength from point load strength. The point load strength test is a form of "indirect tensile" test, but this is largely irrelevant to its primary role in rock classification and strength characterization. $I_{s(50)}$ is approximately 0.80 times the uniaxial tensile or Brazilian tensile strength.

2. Of the four alternative forms of this test, the diametral test and the axial test with saw-cut faces are the most accurate if performed near the standard 50 mm size, and are preferred for strength classification when core is available. Axial test specimens with saw-cut faces can easily be obtained from large block samples by coring in the laboratory. Specimens in this form are

ISRM: POINT LOAD TEST

Sample Details — Point Load Test — Date 17/11/83

1 block sample from Gamblethorpe Opencast site.

Fine grained pale grey Coal Measures sandstone with numerous coaly streaks along horizontal bedding planes.

Specimens 1-6 chisel cut blocks, air-dried 2 weeks;
7-10 saw blocks, air-dried 2 weeks;
11-15 cores, air-dried 2 weeks;
16-20 cores, air-dried 2 weeks;
- tested in laboratory.

No.	Type	W (mm)	D (mm)	P (kN)	D_e^2 (mm^2)	D_e (mm)	I_s	F	$I_{s\,(50)}$
1	i ⊥	30.4	17.2	2.687	666	25.8	4.03	0.75	~~3.01~~
2	i ⊥	16	8	0.977	163	12.8	5.99	0.54	3.24
3	i ⊥	19.7	15.6	1.962	391	19.8	5.02	0.66	3.31
4	i ⊥	35.8	18.1	3.641	825	28.7	4.41	0.765	3.46
5	i ⊥	42.5	29	6.119	1569	39.6	3.90	0.875	3.49
6	i ⊥	42	35	7.391	1872	43.3	3.95	0.935	~~3.69~~
7	b ⊥	44	21	4.600	1176	34.3	3.91	0.84	3.29
8	b ⊥	40	30	5.940	1528	39.1	3.88	0.89	3.46
9	b ⊥	19.5	15	2.040	372	19.3	5.48	0.655	~~3.59~~
10	b ⊥	33	16	2.87	672	25.9	4.27	0.75	~~3.20~~
11	d //	-	49.93	5.107	-	-	-	-	2.05
12	d //	-	49.88	4.615	-	-	-	-	1.85
13	d //	-	49.82	5.682	-	-	-	-	~~2.29~~
14	d //	-	49.82	4.139	-	-	-	-	~~1.67~~
15	d //	-	49.86	4.546	-	-	-	-	1.83
16	d //	-	25.23	1.837	-	-	2.89	0.74	2.14
17	d //	-	25.00	1.891	-	-	3.02	0.735	2.22
18	d //	-	25.07	2.118	-	-	3.37	0.735	~~2.48~~
19	d //	-	25.06	1.454	-	-	2.32	0.735	~~1.70~~
20	d //	-	25.04	1.540			2.46	0.735	1.81

d = diametral;
a = axial;
b = block;
i = irregular lump test;
⊥ = perpendicular;
// = parallel to planes of weakness.

Mean $I_{s\,(50)}$ ⊥	3.38
Mean $I_{s\,(50)}$ //	1.98
$I_{a\,(50)}$	1.71

Fig. 8. Typical results form.

particularly suitable when the rock is anisotropic and the direction of weakness planes must be noted.

3. Loads of up to 50 kN are commonly required for the larger hard rock specimens. The maximum specimen size that can be tested by a given machine is determined by the machine's load capacity, and the smallest by the machine's load and distance measuring sensitivity. Tests on specimens smaller than $D = 25$ mm require particular precautions to ensure that the measuring sensitivity is sufficient. The range of required test loads should be estimated before testing, from approximate assumed strength values, to ensure that the load capacity and sensitivity of the equipment are adequate. It may be necessary to change the load measuring gauge or load cell, or to test smaller or larger specimens to conform with the capacity of available equipment or with the accuracy specifications for this test.

4. The conical platen design is intended to give standardized penetration of softer specimens. When testing is confined to hard rocks and small (less than 2 mm) penetrations the conical design is unimportant provided that the tip radius remains at the standard 5 mm. For such testing the platen can be manufactured by embedding a hard steel or tungsten carbide ball in a

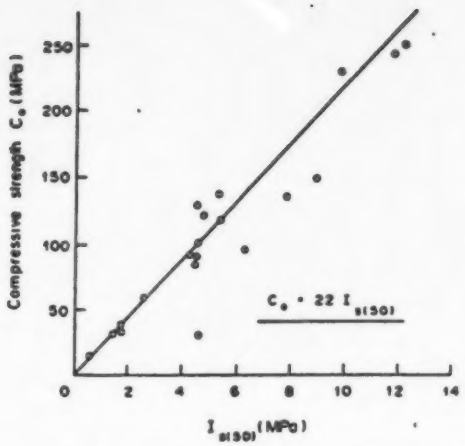

Fig. 9. Example of correlation between point load and uniaxial compressive strength results.

softer metal base of any geometry that will ensure that only the platen tip is in contact with the rock.

5. If a quick-retracting ram is used to reduce the delay between tests, either the ram return spring force and ram friction should together be less than about 5% of the smallest load to be measured during testing, or an independent load cell rather than an oil pressure gauge should be used for load determination. These forces can be significant when testing weaker and smaller specimens.

6. If significant platen penetration occurs, the dimension D to be used in calculating point load strength should be the value D' measured at the instant of failure, which will be smaller than the initial value suggested in paragraphs 8(d), 9(d) and 10(d). The error in assuming D to be its initial value is negligible when the specimen is large or strong. The failure value may always be used as an alternative to the initial value and is preferred if the equipment allows it to be measured (for example by electrical maximum-indicating load and displacement measurement). When testing specimens that are smaller than 25 mm, such as rock aggregate particles, equipment with electrical readout is usually necessary to obtain the required measuring accuracy, and should be designed to record D' at failure. Measurements of W or D made perpendicular to the line joining the platens are not affected and are retained at their original values. The value of D_e for strength calculation can then be found from:

$$D_e = D \times D' \quad \text{for cores}$$

$$D_e^2 = \frac{4}{\pi}(W \times D') \quad \text{for other shapes}$$

7. Because this test is intended primarily as a simple and practical one for field classification of rock materials, the requirements relating to sample size, shape, numbers of tests etc, can when necessary be relaxed to overcome practical limitations. Such modifications to procedure should however be clearly stated in the report. It is often better to obtain strength values of limited reliability than none at all. For example, rock is often too broken or slabby to provide specimens of the ideal sizes and shapes, or may be available in limited quantities such as when the test is used to log the strength of drill core. In core logging applications the concept of a "sample" has little meaning and tests are often conducted at an arbitrary depth interval, say one test every 1 m or 3 m depending on the apparent variability or uniformity of strength in the core and on the total length of core to be strength-logged.

8. As for all strength tests on rocks, point load strength varies with the water content of the specimens. The variations are particularly pronounced for water saturations below 25%. Oven dried specimens, for example, are usually very much stronger than moist ones. At water saturations above 50% the strength is less influenced by small changes in water content, so that tests in this water content range are recommended unless tests on dry rock are specifically required.

All specimens in a sample should be tested at a similar and well-defined water content, and one that is appropriate to the project for which the test data are required. Field testing of chisel-cut samples, not affected by drilling fluids, offers a method for testing at the *in situ* water content. If possible, numerical values should be given for both water content and degree of saturation at the time of testing. The ISRM Suggested Method for Water Content Determination should be employed. Whether or not water content measurements can be made, the sample storage conditions and delay between sampling and testing should be reported.

9. Some researchers argue in favour of measuring W as the minimum dimension of the failure surface after testing rather than of the specimen before failure (the German standard for this test is an example). Point load strengths computed using the two alternative W definitions may differ slightly. The minimum specimen dimension alternative has been adopted in this Suggested Method mainly because it is quicker and easier to measure, particularly in the field when fragments of broken specimens are easily lost.

10. Commonly the shortest dimension of naturally occurring anisotropic rock lumps is perpendicular to the weakness planes.

11. The size correction factor chart (Fig. 7) is derived from data on cores tested diametrally and axially and from tests on blocks and irregular lumps, for rocks of various strengths, and gives an averaged factor. Some rocks do not conform to this behaviour, and size correction should therefore be considered an approximate method, although sufficient for most practical rock classification applications. When a large number of tests are to be run on the same type of rock it may be advantageous to first perform a series of tests at different sizes to obtain a graph of load vs D_e^2 as in Fig. 6. If the slope of such a log–log graph is determined as "n", the size correction factor is then $(D_e/50)^m$ where $m = 2(1 - n)$. This can either be calculated directly or a chart constructed.

12. Mean results for small populations are generally better measures when the extreme values are not included in the calculation.

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